SIMULATION SUPPORTING SOFTWARE FOR HITOMI/XARM USER GUIDE

Version 1.0

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X-ray Astrophysics Laboratory (NASA/Goddard Space Flight Center)
and the
Institute of Space and Astronautical Science (ISAS/JAXA)

Prepared by: Hitomi/XARM Science Data Center

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1. Introduction

This guide describes how to make simulations for the upcoming XARM mission using either the simulation tools package and/or the response and arf appropriate for XARM. This version includes only support for the *Resolve* instrument, the calorimeter, on XARM.

The software package consists of: *heasim,* a multi-mission event generator for high energy focusing telescopes; *skyback,* a multi-mission high-energy astrophysics simulator for the sky background; and *sxsbranch,* a calculator of the event grade developed for the SXS on Astro-H/Hitomi but valid also for the *Resolve* instrument on XARM since it has the same instrument characteristics. The support files are copyes either of files used for the ASTRO-H simulations or new ones generated for XARM, however the FITS keywords for telescope and detector are kept as HITOMI and SXS respectively.

The following sections contain the software installation instructions in section 2, the description of *heasim*, *skyback,* and *sxsbranch* in sections 3, 4, and 5, respectively. Appendices A and B are devoted to detailed examples of input, output, and data products for a variety of simulations. There are some simulations that are specific for XARM and others for all instruments on Astro-H.

The SXS instrument and telescope characteristics are published in the SPIE proceeding and can be found at http://heasarc.gsfc.nasa.gov/docs/hitomi/about/paper_list.html. The calorimeter and telescope on XARM have the same characteristics of the SXS and telescope on Hitomi.

2. Installation

The package includes three tar files, containing the software simulation package, the support files and example scripts. They are:

1. xarm_prop_16Aug2017_V001_src.tgz software package
2. heasimfiles_20170830.tar.gz support files for the software and responses
3. heasimscripts_20170830.tar.gz scripts for simulation as described in appendix B

The software package contains all the necessary tasks (*heasim*, *skyback,* and *sxsbranch)* and libraries to simulate the event files as well as the XSPEC spectral fitting program and XSELECT to extract high level product the event files. These tasks are included in the latest HEASoft 6.22. If the user has already installed HEAsoft 6.22 does not need to install this software package, however need the support files and scripts to run *heasim* and/or XSPEC.

The procedure to install the software is identical to that of HEASoft and available from http://heasarc.gsfc.nasa.gov/lheasoft/install.html. A short version of the software installation procedure is in the XARM_prop_V001_install.txt file provided in the same directory of the xarm_prop_16Aug2017_V001_src.tgz tar file.

To install the scripts and support files tar files the steps are the following:

1) Download and unpack the support and sample script tar files in any directory

```
tar -xvzf heasimfiles_20170830.tar.gz
tar -xvzf heasimscripts_20170830.tar.gz
```

This creates two directories, heasimfiles/ and heasimscripts/, in the current directory (pwd command gives you the current directory).

Hereafter, <heasimfilesdir> refers to the **full path** to the directory heasimfiles/, that may be moved to any convenient location.

2) Set the HEASIM_SUPPORT environment variable to run *heasim*:

For C-shell:

```
setenv HEASIM_SUPPORT <heasimfilesdir>
```

For Bash:

```
setenv HEASIM_SUPPORT <heasimfilesdir>
```

3) Set the XSELECT_MDB environment variable to run *xselect* and select the event created with *heasim*.

For C-shell:

```
setenv XSELECT_MDB $HEASIM_SUPPORT/auxiliary/xselect.mdb.heasim
```

For Bash:

```
export XSELECT_MDB=$HEASIM_SUPPORT/auxiliary/xselect.mdb.heasim
```

2.1 Run Simple Test Cases

Case (a), running a *heasim* test case:

```
cd <top-dir>/heasimscripts
sh run_sim.sh >& run_sim.log
```

This creates an output subdirectory, <top-dir>/heasimimscripts/output, if it does not exist, and places the output fits file astroH_sxi_plaw.fits into that subdirectory. The run details are logged in run_sim.log. The script “run_sim.sh” may be used as template to create different simulation recipes.

Case (b) running a *skyback* test case:

```
cd <top-dir>/heasim/skyback
sh run_skyback.sh >& skyback.log
```

This creates the following *skyback* output files in the working directory: pscat_heasim.txt, difcat_heasim.txt, difspec_heasim.dat, difspec_heasim.fits, and pszcat_heasim.txt. The run details are logged in skyback.log. The "run_skyback.sh" script may be used as a template to create different background simulations.

3. Heasim

Heasim is a multi-mission high-energy astrophysics simulation tool. *Heasim* utilizes a pseudo-monte-carlo approach that redistributes the source photons in position and energy according to the input files appropriate to the chosen telescope/detector system. The output is a FITS event file, from which data products may be extracted and analyzed using, e.g., XSELECT, XSPEC, etc. *Heasim* uses a parameter file similarly to the other FTOOLS where parameters can be set either at the prompt, set on the command line, or pre-set using *pset. Heasim* is, in part, based on the simulation procedures that were available within XIMAGE and the QUICKSIM simulator for XMM-NEWTON.

The parameters *mission* and *instrume* are for specifying the mission name and the instrument names for that mission. The specific characteristics of the supported instruments (e.g, pixel size, field-of-view, etc.) are collected in the mission database file (parameter *mdbfile*). The parameters *rapoint, decpoint* define the center of the field of view, and the *roll* parameter the rotation angle (all in decimal degrees). The exposure time in seconds is entered in as the parameter *exposure.* The source(s) position; and spectral, spatial, and temporal characteristics are input via the source definition file (parameter *insrcdeffile*). Point spread function, vignetting, spectral response, effective area, and internal background for each detector are input using the parameters *psffile*, *vigfile, rmffile, arffille*, and *intbackfile*, respectively (allowed formats described below). The sky background may be calculated using the *skyback* tool and the output files from *skyback* may be input to *heasim.* The parameter *psbackfile* accepts a file containing a list of the resolved background point sources as calculated and output by *skyback*. The parameter *pszbackfile* accepts a file that lists the point source intrinsic redshifts and absorptions for these same sources. The parameter *difbackfile* accepts the file that lists a single diffuse background extended source as calculated and output by *skyback*. The simulation may be split into multiple subexposures by setting the *flagsubex* parameter to yes, and the s*ubexpsosure* parameter to a value that differs from *exposure*. Resampling of event locations from sky pixels onto larger detector pixels is controlled by the *resample* parameter. The discarding of events outside of the field-of-view may be skipped using the *skipfov* parameter. Basic event pileup may be calculated using the *dtpileup* timescale parameter in units of seconds. The *heasim* parameters are described in full detail below.

Heasim calculates simulated events for each input source in the source definition file (and background) with the following steps. (1) The absorbed input spectrum (in photons cm^{-2} s^{-1} vs

keV) based on the input spectral model or user spectrum file is calculated in each energy bin in the arf file. (2) This is then converted to cts/bin vs bin on this input energy grid by multiplying by the exposure time and effective area. (3) The sum over all bins yields the total number of events. For each source, the code loops over each input energy bin, and over the counts in each bin (4) probabilistically assigning a sky position to each event according to the source spatial distribution. This distribution may be determined either by a model or by an input image (or subimage). (5) An event may be discarded based on the vignetting, and (6) "scattered" by the PSF. (7) Events are discarded if located outside the FOV, and (8) assigned final discrete sky coordinates that are resampled within detector pixels unless resampling is switched off. For each energy bin, (9) the rmf is used to redistribute the input energy and assign output PI values for each photon not discarded due to vignetting or falling outside the FOV. These events are then (10) assigned times according to the source temporal characteristics (constant, periodic, or burst). Sky background sources, i.e. from the output of *skyback*, are identically processed. Internal background events from the input internal background spectrum, following rescaling to the detector area and observation exposure time, are assigned random detector locations and times within the exposure. Events from all sources and from the internal background are merged and sorted on time, with an option to identify pileup. If the simulation is split into subexpsoures, this procedure is repeated for each subexposure, with the time-sorting, pileup calculation, and final output completed within each interval to reduce memory usage.

The *heasim* output events file contains the following columns: the time of the event, TIME, the sky coordinates, X and Y, the energy channel PI, and a flag set to 1 if the event is piled up (and 0 otherwise), PILEUP.

3.1 Source Definition File

The "source definition file" allows one to specify the spatial, spectral, and temporal characteristics of the source(s) to be simulated. This file is always required. This is an ascii file where each row contains parameters, separated by commas, and is dedicated to a single source. The format of each row is:

ra, dec, NH, spec_mod, spec_par, flux, bandpass, filename, format, units, **source_specs**

where *ra* and *dec* identifies the position of the source to simulate (degrees), and NH is the column density (e.g., 1.0e22). The spectral characteristics may be specified in two different ways: (a) as a single component spectral model with one spectral parameter, and flux in a specified energy band, using the parameters *spec_mod*, *spec_par, flux,* and *bandpass* (see description below); or, alternatively (b) a spectrum can be input using the parameters *filename, format,* and *units* (see description below). The final parameter *source_specs* is used to define temporal, or complex spatial, source characteristics. All of these parameters are required, except for *source_specs* as described below.

Spectral characterstics
(a) A spectral model may be input using the *spec_mod*, *spec_par, flux* and *bandpass* parameters. These must be set as follows: *spec_mod* is a spectral model specified as an XSPEC-like string,

spec_par is the value of the parameter of the spectral model, *flux* is the flux value in erg cm^{-2} s^{-1}, and *bandpass* is the lower and upper energy range over which the flux is defined (lower and upper limits in keV, separated by a dash). Spectral models are calculated using the XSPEC library. Table 1 lists the supported single parameter spectral models.

Table 1 Spectral Models Supported by *Heasim*

Model (spec_mod)	**Parameter**	**Flux**	**bandpass**
Power (pow, plaw, etc.)	index	flux (erg cm^{-2} s^{-1})	Emin-Emax (keV)
Blackbody (bb, bbod, etc.)	kT (keV)	flux (erg cm^{-2} s^{-1})	Emin-Emax (keV)
Bremsstrahlung (brem, etc.)	kT (keV)	flux (erg cm^{-2} s^{-1})	Emin-Emax (keV)
Thermal Plasma (rs, ray, etc.) [Raymond-Smith]	kT (keV)	flux (erg cm^{-2} s^{-1})	Emin-Emax (keV)
Mono-energetic (mono)	E (keV)	flux (erg cm^{-2} s^{-1})	Emin-Emax (keV)

If Emin=0 the lower bandpass limit for the input flux is set to the minimum instrument energy (simulated as defined by the input arf file), and if Emax=0 the upper bandpass limit for the input flux is set to the maximum instrument energy.
NOTE: To enable the spectral model option, the parameter *filename* should be set to "none", and the parameters *format* and *units* are ignored.

(b) As an alternative to the spectral model described above in (a), spectral files that describe more complex spectra may be input. For the spectral file option, the following parameters must be set: *filename, format* and *units*. *filename* is the name of spectral file. Two formats are supported. If the parameter *format* is set to 1, the first two columns are assumed to be (a) energy bin center, and (b) flux in the bin. This follows the output from the SHERPA "save_chart_model" command. If the parameter *format* is set to 2 or 3, the first three columns are assumed to be (a) energy or wavelength bin center, (b) energy or wavelength bin half-width, (c) flux in the bin. This is output from XSPEC using the sequence of commands "iplot model/wdata" (*format*=2) or "setplot wave perhz off/plot model/iplot/wdata" (*format*=3). The flux units of the spectral file are specified in the parameter *units*. The allowed units are listed in Table 2.

Table 2 Units for Spectral Files

spectral file units flag	**energy column(s) unit**	**flux column units**
1	keV	photons cm^{-2} s^{-1} $chan^{-1}$ [SHERPA]
2	keV	photons cm^{-2} s^{-1} keV^{-1} [Xspec]
3	angstroms	photons cm^{-2} s^{-1} A^{-1} [Xspec]
4	eV	ergs cm^{-2} s^{-1} eV^{-1}
5	keV	ergs cm^{-2} s^{-1} keV^{-1}
6	angstroms	ergs cm^{-2} s^{-1} A^{-1}
7	eV	ergs cm^{-2} s^{-1} $chan^{-1}$
8	keV	ergs cm^{-2} s^{-1} $chan^{-1}$
9	angstroms	ergs cm^{-2} s^{-1} $chan^{-1}$

NOTE: To enable the spectral file, the parameter *spec_mod* should be set to "user", and the parameters *spec_par*, *flux*, and *bandpass* are ignored.

As an example, the following sequence of XSPEC commands produces a suitable ASCII file for a 2 keV, half-solar abundance APEC thermal model absorbed by column density $N_H = 10^{21}$ cm^{-2} with the Tuebingen-Boulder ISM absorption cross section. The norm is adjusted to yield an absorbed flux of 10^{-11} erg cm^{-2} s^{-1}, and the model is evaluated on an energy grid of 12000 points between 0.1 and 12.1 keV. The "myspec.qdp" file may be directly imported into *heasim.* In this case the format and units entries in the source definition file should both be set to 2. That is, for a point source at (ra,dec)=(150.0,30.0) with this spectrum, the source defintion file might look like the following where, because the absorption is included in the user file, N_H is set to 0:

150.0, 30.0, 0.0e0, user, 0.0, 1.0e-11, 0.1-12.0, myspec.qdp, 2,2

```
XSPEC12>abund aspl
 Solar Abundance Vector set to aspl:  Asplund M, Grevesse N., Sauval A.J. & Scott P., 2009, ARAA, 47, 481
XSPEC12>model tbabs*apec

Input parameter value, delta, min, bot, top, and max values for ...
        1     0.001(     0.01)        0        0    100000     1e+06
1:TBabs:nH>.1
        1      0.01(     0.01)     0.008     0.008       64       64
2:apec:kT>2
        1    -0.001(     0.01)        0        0        5        5
3:apec:Abundanc>.5
        0     -0.01(     0.01)    -0.999    -0.999       10       10
4:apec:Redshift>.03
        1      0.01(     0.01)        0        0     1e+20     1e+24
5:apec:norm>

========================================================================
Model TBabs<1>*apec<2> Source No.: 1   Active/Off
Model Model Component  Parameter  Unit     Value
 par  comp
   1   1  TBabs     nH        10^22    0.100000    +/-  0.0
   2   2  apec      kT        keV      2.00000     +/-  0.0
   3   2  apec      Abundanc           0.500000    frozen
   4   2  apec      Redshift           3.00000E-02  frozen
   5   2  apec      norm               1.00000     +/-  0.0
------------------------------------------------------------------------

XSPEC12>flux .3 10
 Model Flux   0.41778 photons (8.577e-10 ergs/cm^2/s) range (0.30000 - 10.000 keV)
XSPEC12>new 5 .0117
XSPEC12>flux .3 10
 Model Flux 0.0048881 photons (1.0035e-11 ergs/cm^2/s) range (0.30000 - 10.000 keV)
XSPEC12>energ 0.1 12.1 12000

Models will now use energy array created from:
   0.1 - 12.1   12000 linear bins
```

```
XSPEC12>iplot model
PLT> wdata myspec.qdp
PLT> quit
```

Note that the flux is set by sum of the flux-per-bin column in the input spectrum, and it (and the bandpass) need not be set in the source definition file. However they must be set if the user chooses to run the simulation with optimized subexposures (see below), since the flux is used to calculate the duration per subexposure.

Additional source characteristics: source_specs

Timing or spatial characteristics for sources may be added using a particular string in place of "**source_specs".**

The specific strings are :

pulse(period, pulse_frac)
burst(tburst, risetime, decaytime, burstratio)
extmod(**beta**, beta, core_radius, ellipticity, pos_angle, Rmin, Rmax)
extmod(**ellipse**, ellipticity, pos_angle, Rmin, Rmax)
extmod(**power**, slope, Rmin, Rmax)
extmod(**gauss**, fwhm_x, fwhm_y, pos_angle)
extmod(**flat**, Rmin, Rmax)
image(filename, xmin, xmax, ymin, ymax)

Pulse and **burst** are used to describe timing characteristics for point sources. **Pulse** is for periodic variation where *period* is the period in seconds and *pulse_frac* is the pulse fraction. **Burst** is for simulating bursts, where *tburst* is the time in seconds when the burst starts with respect to the start of the observation, *risetime* is the rise time in seconds (linear), *decaytime* is the exponential decay time in seconds, and *burstratio* is the ratio of the peak-to-quiescent flux. The flux in the source definition file refers to the *average* flux over the exposure time for these time-varying sources.

The **extmod** and **image** specifications may be used to describe extended source models or an input image. These options require the parameters listed in Table 3.

Table 3 Spatial Distribution Parameters

Model	**par1**	**par2**	**par3**	**par4**	**par5**	**par6**
point	...	...	...	...	...	...
beta	beta	rcore	ellipticity	position angle	Rmin	Rmax
flat	Rmin	Rmax	...	...	...	...
ellipse	ellipticity	position angle	Rmin	Rmax	...	...
gauss	fwhm_x	fwhm_y	position angle	...	...	...
power	slope	Rmin	Rmax	...	...	...
image	filename	Xmin	Xmax	Ymin	Ymax	...

For the beta-model distribution, the flux is distributed according to the equation $[1+x^2/r_{core}^2+y^2/(e^2r_{core}^2)]^{-3\beta+0.5}$. The **beta**-model parameters are as follows: (1) beta parameter β; (2) core_radius in arcmin (r_{core}); (3) ellipticity (e); (4) pos_angle is the position angle, counterclockwise sky to major axis (ra to dec); (5) Rmin = minimum radius (along major axis) in arcmin; and, (6) Rmax = maximum radius (along major axis) in arcmin. For **flat** models the flux is evenly spread over an annulus; and, the only parameters are (1) Rmin = minimum radius in arcmin; and, (2) Rmax = maximum radius in arcmin. For **ellipse** the ring models parameters are (1) ellipticity; (2) position angle, counterclockwise sky to major axis (ra to dec); (3) Rmin = minimum radius (along major axis) in arcmin; and; (4) Rmax = maximum radius (along major axis) in arcmin. For (2d) **gauss**ian models parameters are (1) fwhm_x in arcmin; (2) fwhm_y in arcmin; and, (3) position angle, counterclockwise sky to x (ra to dec). For **power**-law distributions, parameters are (1) the power-law slope; (2) Rmin = minimum radius in arcmin, and (3) Rmax = maximum radius in arcmin. Note that these position angles are defined "ra-to-dec" not "-ra-to-dec." For the **image** option the parameters are the input fits image filename, and coordinates in units of pixels to define a subimage in the file: Xmin, Xmax, Ymin, Ymax. To consider the entire image one may set Xmin=Ymin=Xmax=Ymax=0. Several examples of source definition files may be found in the files in $HEASIM_SUPPORT/testdata/source_data -- multiple examples are include in heasim_source_sample.txt, and the above explanatory information is encapsulated in heasim_source_header.txt.

3.2 The Mission Database File

The mission database file heasim.mdb contains characteristics of the supported instruments. The default file is located in $HEADAS/../heasim/<machine-architecture>/refdata. The heasim.mdb entries are listed in Table 4a, and the values (to four significant digits) for the Hitomi instruments, adapted from early version of their respective teldef files, in Table 4b. Note that, since heasim.mdb explicitly references the instrument maps in the supporting files directory tree, these must be available and the HEASIM_SUPPORT environment variable set accordingly.

Table 4a Mission Database Entries

FOV_RADIUS	Detector FOV radius in arcmin, used to discard sources that fall outside of the detector if there is no instrument map
FOCALLEN	Telescope focal length in mm
PSF_FWHM	FWHM in arcsec for a gaussian approximation to the PSF, used for file_psf=Gaussian option
DET_XSCL	Detector pixel size, x, in mm
DET_YSCL	Detector pixel size, y, in mm
DET_XNPIX	Number of detector pixels, x
DET_YNPIX	Number of detector pixels, y
HEA_XPIXSIZ	Pixel size in degrees, x, for *heasim* internal coordinates
HEA_YPIXSIZ	Pixel size in degrees, y, for *heasim* internal coordinates
HEA_XNPIX	Number of *heasim* internal coordinate pixels, x
HEA_YNPIX	Number of *heasim* internal coordinate pixels, y
SKY_XPIXSIZ	Pixel size in degrees, x, for sky coordinates
SKY_YPIXSIZ	Pixel size in degrees, y, for sky coordinates

SKY_XNPIX	Number of sky_x pixels
SKY_YNPIX	Number of sky_y pixels
FOC_XPIXSIZ	Focal plane coordinate pixel size in degrees, x
FOC_YPIXSIZ	Focal plane coordinate pixel size in degrees, y
FOC_XNPIX	Number of focal plane coordinate pixels, x
FOC_YNPIX	Number of focal plane coordinate pixels, y
OPTAXIS_FOCX	Position of optical axis in focal plane coordinate pixels, x
OPTAXIS_FOCY	Position of optical axis in focal plane coordinate pixels, y
AIM_FOCX	Position of aim point in focal plane coordinate pixels, x
AIM_FOCY	Position of aim point in focal plane coordinate pixels, y
FOC_ROTD	Rotation angle of detector in focal plane
FOCX_OFF	Offset of detector origin from origin of focal plane coordinate, x
FOCY_OFF	Offset of detector origin from origin of focal plane coordinate, y
INSTMAP	Name of instrument map file

Note: The following heasim.mdb entries that describe the instrument field of view: DET_XNPIX, DET_YNPIX, FOC_ROTD, FOC_XOFF, FOC_YOFF, are used for reampling of simulated photons onto detector pixels when there is no instrument map. All Astro-H/Hitomi and XARM detectors **do** have instrument map mdb entries.

Table 4b Hitomi Instrument Mission Database Entry Values

	SXI	SXS	HXI1	HXI2
FOV_RADIUS	34.0	2.3	6.9	6.9
FOCALLEN	5600.0	5600.0	12000.0	12000.0
PSF_FWHM	78.0	78.0	102.0	102.0
DET_XSCL	0.048	0.832	0.250	0.250
DET_YSCL	0.048	0.832	0.250	0.250
DET_XNPIX	1810	8	256	256
DET_YNPIX	1810	8	256	256
HEA_XPIXSIZ	0.0004911	0.0004911	0.0004911	0.0004911
HEA_YPIXSIZ	0.0004911	0.0004911	0.0004911	0.0004911
HEA_XNPIX	2430	600	600	600
HEA_YNPIX	2430	600	600	600
SKY_XPIXSIZ	0.0004911	0.0004911	0.0004911	0.0004911
SKY_YPIXSIZ	0.0004911	0.0004911	0.0004911	0.0004911
SKY_XNPIX	2430	2430	2430	2430
SKY_YNPIX	2430	2430	2430	2430
FOC_XPIXSIZ	0.0004911	0.0004911	0.0004911	0.0004911
FOC_YPIXSIZ	0.0004911	0.0004911	0.0004911	0.0004911
FOC_XNPIX	2430	2430	2430	2430
FOC_YNPIX	2430	2430	2430	2430
OPTAXIS_FOCX	1215.5	1215.5	1215.5	1215.5
OPTAXIS_FOCY	1215.5	1215.5	1215.5	1215.5
AIM_FOCX	1215.5	1215.5	1215.5	1215.5

AIM_FOCY	1215.5	1215.5	1215.5	1215.5
FOC_ROTD	0.0	0.0	22.5	-22.5
FOCX_OFF	-157.0	-1.0	0.0	0.0
FOCY_OFF	-157.0	-1.0	0.0	0.0
INSTMAP	ah_sxi_instmap_20131001v004.fits	ah_sxs_instmap_20131001v004.fits	ah_hx1_instmap_20131001v00.fits	ah_hx2_instmap_20131001v004.fits

3.3 Calibration Files and Format

Each instrument for each mission has the following associated calibration files: rmf, arf, internal background, psf, vignetting, and instrument map.

The response matrix (rmf) and ancillary response (arf) files are in FITS following the standard format adopted in XSPEC spectral analysis. The internal background spectrum is a FITS standard PHA file where BACKSCAL is defined as the ratio of detector area from which the spectrum is extracted to the total detector area, and the energy channels match those in the EBOUNDS extension of the rmf file. The spectrum should correspond to the full field-of-view of the detector. Similarly, the arf should be simply defined to convert flux in a region on the sky into count rate in the corresponding region on the detector.

The following three types of psf files are supported. (a) A flat ASCII or FITS table with multiple columns, each giving the eef versus radius for a given energy and off-axis angle (defined with respect to the optical axis). The table contains a column named PSFRAD, containing the radial distance from the center of the psf in arcseconds, and columns each providing the eef for a given energy and offaxis angle named EEFxxx where xxx is a three character numerical value padded with 0s, for example EEF001, EEF002, etc. The energy and offaxis angle of the EFF columns are provided in header keywords ENGxxx and OFFxxx where xxx is defined in the same way as the column suffix, for example ENG001 and OFF001, ENG002 and OFF002, etc. The energy is provided in keV and the offaxis angle in arcminutes. (b) A FITS file with separate extensions for a given energy and off-axis angle. Each table contains two columns PSFRAD (radial distance in arcseconds) and EEF. The energy and offaxis angle are in the header keywords ENERGY and OFFAXIS. (c) A FITS file with one bintable extension and several image extensions containing the PSF images at given energy and off-axis angle and azimuthal angle. The bintable has EXTNAME set to PSF and has seven columns, with three identifying the OFFAXIS angle (in arcmin), AZIMUTH (in degrees), and ENERGY (in keV). Each row identifies one IMAGE extension containing a map of the PSF. The image extension header includes the following keywords: OFFAXIS, AZIMUTH, and ENERGY for the offaxis angle, azimuth and energy, and the keywords CRPX1 (X reference pixel for the image), CRVL1 (X reference pixel value in mm), CDLT1 (X pixel scale in mm), CRPX2 (Y reference pixel for the image), CRVL2 (Y reference pixel value in mm), CDLT2 (Y pixel scale in mm) specify the coordinates. All extensions for file type (a) and (b) have the EXTNAME keyword set to EEF, all IMAGE extensions have EXTNAME set to IMAGE_PSF.

Three types of vignetting files are supported. (a) A flat ASCII or FITS table with vignetting versus off-axis angle for a series of energies. The table contains a column named OFFAXIS, containing the radial distance from the optical axis in arcmin, and columns each providing the vignetting for a given energy named VIGxxx, where xxx is three character numerical value padded with 0s, for example VIG001, VIG002, etc. The energy for the vignetting columns are provided in header keywords ENGxxx where xxx is defined in the same way as the column suffix, for example ENG001, ENG002, etc. The energy is provided in keV. (b) A FITS file with separate extensions for a given energy. Each table contains two columns OFFAXIS (radial distance in arcmin) and VIG containing the vignetting. The energy is in the header keyword ENERGY. (c) A FITS file with one bintable extension and several IMAGE extensions containing the vignetting as an image at a given energy. The bintable has EXTNAME set to VIGNETTE and has one column ENERGY (in keV). Each row identifies one IMAGE extension containing a map of the vignetting. The keyword ENERGY in the IMAGE extension header specifies energy for the image and the keywords CRPX1 (X reference pixel for the image), CRVL1 (X reference pixel value in mm), CDLT1 (X pixel scale in mm), CRPX2 (Y reference pixel for the image), CRVL2 (Y reference pixel value in mm), CDLT2 (Y pixel scale in mm) specify the coordinates. All extensions have the EXTNAME keyword set to VIGNETTE for options (a) and (b), and VIG_IMAGE for option (c).

Instrument maps define the field-of-view of the detector, and are referenced in the *heasim* mission database file. The instrument map is a FITS image, where the image is in (FOCX, FOCY) coordinates, and has value 1 within the detector and 0 outside the detector.

3.4 Options for Mitigating Memory Issues

Heasim holds the simulated events and their characteristics in memory to allow sorting before writing to the output file. Depending on the computer capabilities, simulations of extremely bright sources may not run to completion because of insufficient computer memory. There are two options for reducing memory usage in *heasim*.

The first option is to set the *flagsubex* parameter to "yes" and the *subexposure* parameter to a value different than the *exposure* parameter. When this option is applied, *heasim* processes the simulated events within the time specified in the subexposure, writes these events to the output file and proceeds to the next subexposure. If the *subexposure* is equal to the *exposure* parameter all events are processed together (even for *flagsubex*=yes). If *subexposure* > *exposure*, the subexposure durations are "optimized" by *heasim*to have less than 500,000 counts per subexposure. By default, the parameters *flagsubex* and *subexposure* are set to allow the "optimization" mode *(flagsubex=yes* and *subexposure* =1.0e9).

The second option is to use the script *divide_flux.pl* included in the distribution (ahsimscripts directory). The script effectively runs several *heasim* sessions, creating separate files and combining them at the end of the simulations. *This option was implemented to facilitate simulation of bright variable sources; however using subexposures as described above now handles variable source and is the recommended method.* The script needs to be edited to include the desired *heasim* input parameters and the "rootname" for output events files. After that, the

script may be run as "*divide_flux.pl N"* where "N" is the number of *heasim* sessions needed to complete the simulation. The *divide_flux.pl* script creates a source definition file with the flux reduced by N, and runs N reduced-flux simulations. Following the completion of all simulations the output files are merged into a single fits file using *ftmerge*, and then sorted on time using *ftsort*. When using this script, the internal and sky backgrounds should be set to "none" otherwise, they would be included in full for each simulation and hence overestimated by the N factor. A logfile, "rootname.log," is also created.

3.5 Running Heasim and "Post-Processing"

Heasim uses a parameter file in a similar way to that of other FTOOLS. Parameters may be set either in response to a prompt, set on the command line, or pre-set using *pset.* Utilization of scripts, such as run_sim.sh or the scripts used to run the examples in Appendix B greatly streamlines the operation of repeated simulations, e.g. those for the same source using different detectors and is highly recommended. All of these are included in the ahsimscripts directory.

The event files can be analyzed in the usual way using XSELECT, XSPEC, etc. To use XSELECT in a shell where the HEASIM_SUPPORT environmental variable is set, one should issue the command

setenv XSELECT_MDB $HEASIM_SUPPORT/auxiliary/xselect.mdb.heasim (C-shell),

or

export XSELECT_MDB=$HEASIM_SUPPORT/auxiliary/xselect.mdb.heasim (Bash).

For the user to use XSELECT in a location where the HEASIM_SUPPORT environmental variable is not set, xselect.mdb.heasim ought to be copied to the working directory from $HEASIM_SUPPORT/auxiliary, or the full directory path should be specified.

Since the output file coordinates (x,y) are in SKY coordinates, in XSELECT one should

set wmapname x y

prior to extracting a spectrum from an event file, and any region filtering must be applied using SKY or WCS coordinates.

3.6 Using Heasim for XARM simulations

The support files to model the calorimeter and telescope on XARM are included in the heasimfiles.tar.gz. These files are necessary to run *Heasim*, *sxsbranch* as well as to use within XSPEC simulation. The tar file may be untarred in a location convenient to the user (<mydir>). It creates a directory named heasimfiles/ and the following environmental variable may be set as:

setenv HEASIM_SUPPORT <mydir>/heasimfiles (C-shell).

.

The XARM support files are included in the heasimfiles subdirectory "hitomi" and contains only support file for the calorimeter. Although XARM is a new mission for the poupose of this simulation package the directory is named 'hitomi' since the characteristics of the XARM calorimeter, *Resolve,* are taken from the Hitomi SXS. Therefore the naming within the FITS files for the TELESCOP and INSTRUME are HITOMI and SXS respectively and the event simulated with *heasim* have these keywords set in the same way. The content of the directory is listed in Table 5.

Table 5 XARM Supporting Files for Simulation

Filename **XARM Resolve/ Hitomi SXS**	**Description and Provenence**
response/ xarm_res_h5ev_20170818.rmf xarm_res_h7ev_20170818.rmf xarm_res_m6ev_20170818.rmf xarm_res_m8ev_20170818.rmf	These are the responses simulated for XARM only the core of the line spread function is included. The resolution of the core for the High grade is either 7eV and 5eV that correspond to the required and the goal resolution respectively (files with h5v and h7eV). The other two files (m6eV and m8eV) have the sam e mening for the Medium grade.
xarm_res_pnt_fa_20170818.arf xarm_res_flt_fa_20170818.arf xarm_res_bet_fa_20170818.arf xarm_res_pnt_pa_20170818.arf xarm_res_flt_pa_20170818.arf xarm_res_bet_pa_20170818.arf	These are the arf files simulated for XARM using the characteristics of the Hitomi telescopes, the quantum efficiency and the optical blocking filter of the SXS detector. The gate valve is open and not other filters are applied. The file naming convension is the following : * *pnt* is used for a point source ARFs * *flt* and *bet* are used for an extended source ARFs with either a flat distribution or following a beta model distribution. * *fa* is used for the full SXS array (about ~3 arcmin sq) and contains 80% of the source PSF . These are suitable for XSPEC simulation. * *pa* is used for the the full PSF and suitable for simulation with *heasim*. *(see additional text after the table)*
background/ hitomi_nxb_sxs.pha	This is the Non X-ray background derived from the inflight SXS Hitomi data taken after March 4, 2016 after the temperature of the detector reached the nominal operating temperature. *(see additional text after the table)*
instmap/ ah_sxs_instmap_20131001v004.fits	This file is used in *heasim* and it is the field of view of the SXS detector
vignette/ SXT_VIG_140618.txt SXT_VIG_140618_type1.fits SXT_VIG_140618_type2.fits	These files are necessary for *heasim*. This vignetting function is the pre-flight Astro-H expressed by a Lorentian function. The FWHM as function of energy is Energy(keV) FWHM(arcmin) 1.5 15.73 4.51 15.21 8.04 11.76 9.44 9.61 11.07 8.29 12.94 7.42 For the energy < 10 keV, this is good out to 32 arcmin off-axis angle with about 5% accuracy. But for the energy > 10 keV, the data deviates from the Lorentzian at off-axis > 8 arcmin.

	The files contain the same information but given in different format * SXT_VIG_140618.txt plain ascii * SXT_VIG_140618_type1.fits one FITS extension with several columns one for a specific energy * SXT_VIG_140618_type2.fits several FITS extensions one for each energy
psf/ sxs_psfimage_20140618.fits eef_from_sxs_psfimage_20140618.fits	These files are necessary for *heasim* * sxs_psfimage_20140618.fits are images of the Astro-H PSF derived for on-axis position at energy 1.5 , 4.5, and 8 keV and at 4.5 arcmin offaxis position at energy 1.5keV. They extend to ~9 arcmin. * eef_from_sxs_psfimage_20140618.fits are the Encircle Energy Function derived form sxs_psfimage_20140618.fits
sxsbranch/ pixfrac.txt pixmap.fits pixmask.txt	These files are required for running *sxsbranch* * pixmap.fits :define pixels that are in electrical proximity * pixfrac.txt -- define the fractional distribution of counts in each pixel of the SXS array . This is calculated from a heasim simulation of a point source with a power law spectrum * pixmask.txt -- to exclude the outer 20 pixels from estimates and calculation of the branching ratios for either real or simulated event files.

The Appendix B shows examples of how to use these files for event simulation with *heasim* and XSPEC.
The instrument background spectrum hitomi_nxb_sxs.pha, has been derived from the inflight data. It has a very low count rate and the number of counts per bin is in the Poisson regime. Therefore, it cannot be used directly to include instrument background in simulated spectra. However, it can be used to assess the level of the background compared to a source spectrum, at any energy in the 0.5-12 keV range. Alternatively, the background can be modeled, and the model can be added to a source model in order to simulate spectra of the source and background together.

RMF files are available for two grades (H, or high-resolution, and M, or medium resolution). For each grade, RMF files are available for two spectral resolution values. For the H-grades, these are 5 and 7 eV FWHM, which corresponds to 6 and 8 eV FWHM for M-grades. There are two ARF files for each spatial distribution, one for use in XSPEC, and one for use with '*heasim*'. The ARF files for use with XSPEC (which have the string "_fa_" in the file name), have a normalization that corresponds to events falling only inside the detector region. The ARF files for use with '*heasim*' (which have the string "_pa_" in the file name), have a normalization that corresponds to events falling on the entire focal plane with no region selection.
ARF files are available for three types of source spatial distribution (point source, uniform flat distribution, and a beta-model distribution). The flat distribution is for a radius of 5 arcmin and the beta model has a source radius of 5.7 arcmin, a core radius of 1.26 arcmin and β=0.53.
The beta-model ARF is only valid for a beta-model that has the exact beta-model parameters that were used to make the ARF.

The fluxes measured from spectra made with ARFs for extended source models (the flat model and beta model) correspond to the flux from the exact region for which the ARF was made.

Thus, for example, the 2-10 keV flux for a spectrum made with one of the beta-model ARFs, is the flux from a circle of radius 5.7 arcmin centered on the source.

For the three spatial models, the ratios of number of events inside the detector region to the total number of events in the focal plane are as follows:

Point source: 0.865
Flat model: 0.224
Beta model: 0.464

3.7 Parameters for heasim

mission [string]:
Name of the Mission to be simulated, i.e. Hitomi, Suzaku, XMM. Required.

instrume [string]:
Name of the Instrument to be simulated, i.e. SXS, SXI, HXI, etc. Required.

rapoint [double]:
Right ascension of the pointing position. This may be different from the source right ascension specified in the source definition file. The units are decimal degrees in J2000 epoch. Required.

decpoint [double]:
Declination of the pointing position. This may be different from the source declination specified in the source definition file. The units are decimal degrees in J2000 epoch. Required.

roll [double]:
Rotation angle applied to the y-axis when converting between RA/Dec and coordinates aligned with the detector, i.e. the detector is rotated by Roll Angle from north in the sky. Given in decimal degrees. Required.

exposure [double]:
Exposure time in seconds (i.e. the observation duration). Longer simulation times result in more photons being "detected." Required.

insrcdeffile [string]:
The filename of the source definition file (ASCII) with the source(s) characteristics to simulate. See the "Source Definition File" section. Required.

outfile [string]:
The filename of the simulated output FITS event file. Required.

psffile [string]:

The filename with the point-spread function (PSF) information – either in PSF or EEF form -- for use in the simulation. The file format is either ASCII or FITS (see the calibration files section). If set to "Gaussian", a gaussian psf with FWHM from the mission data base file is used. If set to NONE the photons are not scattered and maintain the original source distribution. Required.

vigfile [string]:
The filename with the vignetting information. The file format is either ASCII or FITS (see the calibration files section). If set to NONE no vignetting is applied. Required.

rmffile [string]:
The filename with the response matrix file (rmf) information. This file gives the probability of a photon of a given energy ending up as a count in a particular (PI) bin of the spectrum. If the parameter is set to NONE, the final energy bin assigned to the event corresponds to the energy grid in the arf file. The file format is FITS (see the calibration files section). Required.

arffile [string]:
The filename with the ancillary response file (arf) information. This file contains the effective area for different energies. The file format is FITS (see the calibration files section). Required.

intbackfile [string]:
The filename with the internal background spectrum of the instrument. The file format is a standard spectral file in FITS format (see the calibration files section). If set to NONE, *heasim* does not add events due to the internal background. Required.

psbackfile [string]:
The filename for the sky background component from resolved background point sources. The file contains, for each source, the sky position and spectral information. These resolved background point sources may be calculated by *skyback*. The format is similar to the source definition file. *Heasim* calculates the events from the background point sources and adds them to the final event file. Optional.

difbackfile [string]:
The filename for the unresolved sky background contribution. The file contains data for the central sky position, radial extent, and name of file for the diffuse spectrum. Both this source file and spectrum for the unresolved background may be calculated by *skyback*. The format is similar to the source definition file. *Heasim* calculates the events from the unresolved background and adds them to the final event file. Optional.

pszbackfile [string]
The filename with the auxiliary data of the resolved background point sources. The file contains redshift and intrinsic absorption column density of the resolved background point sources in *psbackfile.* The format is two columns, with redshift in the first, and intrinsic column density in the second. These may be calculated by *skyback*. If this file is absent, all redshifts and intrinsic absorption column densities are assumed to be 0. Optional.

arfrmftol [double]:
Tolerance required for the agreement of the rmf and arf energy scales. If the tolerance value exceeds the set value, the simulation exits prematurely warning the user. Optional.

flagsubex [Boolean yes/no]:
If set to YES, the simulation is split into multiple observations. This may be used to reduce memory usage. By default, the parameters flagsubex and subexposure are set to allow the "optimization" mode (flagsubex=yes and subexposure =1.0e9). Optional.

subexposure [double]:
Subexposure time in seconds. If *flagsubex* is set to yes, this parameter is used to effectively split the simulation into multiple observations with this duration. If greater than the *exposure* parameter, the subexposure duration is "optimized" such that there are no more than 500,000 estimated counts per subexposure. By default, the parameters flagsubex and subexposure are set to allow the "optimization" mode (flagsubex=yes and subexposure =1.0e9). Optional.

resample [Boolean yes/no]:
If set to YES, the coordinates of simulated photons are recalculated by placing them at a random location within a detector pixel. Optional.

skipfov [Boolean yes/no]:
If set to YES, events outside of the field-of-view of the specifed instrument are not discarded. Optional.

dtpileup [double]:
Timescale for pileup in seconds. Two or more events are flagged if their times are within this timescale and in the same detector pixel. These events are flagged as "pileup" events. Optional.

getinfile[Boolean yes/no]:
If set to YES, heasim_source_sample.txt is copied to the current working directory, and used in place of whatever the source_input_filename parameter was set to. In addition, the pointing determined by the rapoint and decpoint parameters is replaced by the source position. Optional.

filter [string]:
NOT CURRENTLY USED, set to "none". Specifies the instrument filter used.

instmode [string]:
NOT CURRENTLY USED, set to "none". Use to specify for example the CCD readout mode.

seed [integer]
Random number generator seed. If set to zero, the seed is ignored and the RNG is seeded from the system time. Otherwise it is used as given and consecutive applications with identical seed parameter yields identical output.

.

mdbfile [string]:
The filename of the mission database file, which gives mission-specific parameters needed for the simulated observation (see the MDB file section). The default heasim.mdb file may be found under $HEADAS/../<machine-architecture>/refdata. Optional.

clobber [boolean yes/no]:
Overwrites the existing filename if set to yes.

debug [boolean yes/no]:
Diagnostic output is printed on the screen if set to yes.

mode [string]:
Mode to query the parameter file. Acceptable values include: "ql" (query and learn/remember), "hl" (hidden and learn/remember), "q" (query but don't remember), "h" (hidden).

4. Skyback

4.1 Overview

Skyback simulates the discrete and diffuse high-energy astrophysical background over a large energy range. *Skyback* currently includes the following three basic background components, any or all of which may be included. (1) Galactic Halo and Local Hot Bubble (LHB) components are derived (following the QUICKSIM approach) from ROSAT all-sky survey (RASS) surface brightness maps (Snowden et al., ApJ, 485, 125, 1997) to create a model background spectrum appropriate for the part of the sky being observed. The model consists of an absorbed thermal plasma at T_{halo}~$10^{6.6}$ K representing the excess over the extragalactic component seen in the RASS hard bands, plus an unabsorbed thermal plasma at T_{LHB}~10^{6} K representing the additional excess in the soft band. To generate this component, the skyback parameter flaggal must be set to "yes" (its default setting).

(2) Solar Wind Charge Exchange (SWCX) emission may be modeled as either a pure emission-line spectrum, or a continuous spectrum based on DXL sounding rocket measurements of the local galaxy diffuse X-ray emission (Galeazzi et al. 2014, Nature, 512, 171). The parameters that control the SWCX background component are: (a) *flagswcx* which must be set to *yes*, (b) *swcxOVII* and/or (c) *swcxcont* parameters. The *swcxOVII* parameter represents the total flux (in LU; 1 LU == 1 photon cm^{-2} s^{-1} str^{-1}) in the brightest (0.57 keV OVII) feature, and is used as follows. The flux is distributed among the forbidden, resonance, and intercombination OVII lines with the following scaling. F(OVII forbidden 0.5609 keV) = 2/3*F(0.57 keV OVII), F(OVII resonance 0.5740 keV) = 1/6*F(0.57 keV OVII), F(OVII intercombination 0.5685 keV) = 1/6*F(0.57 keV OVII). In addition the OVIII lines are added by scaling this input flux with the following factors: F(OVIII Lα 0.6536 keV) = 0.25*F(0.57 keV OVII), F(OVIII Kβ 0.6657 keV) = 0.083*F(OVIII Lα 0.6536 keV). The *swcxcont* parameter represents the total flux in the 0.2-2 keV band of the continuous SWCX emission, modeled as 0.102 keV thermal (currently, Raymond-Smith) emission, in erg cm^{-2} s^{-1} $arcmin^{-2}$. The norm based on DXL observations

corresponds to the default value 3.17×10^{-16} erg cm^{-2} s^{-1} $arcmin^{-2}$. If *flagswcx* is set to *no*, *swcxOVII* and *swcxcont* parameters are ignored.

(3) The third background component is modeled (based on the XIMAGE simulator) as a two-subcomponent logN–logS distribution of point sources, and is calculated if the parameter *flaglogns* is to *yes* (its default setting). The first logN–logS is a broken power-law designed to allow the inclusion of an extragalactic point-source component. The bright-end slope is determined by the parameter *slopebright1*, the faint-end slope by *slopefaint1*, the flux where the slope changes from *slopebright1* to *slopefaint1* is set by the parameter *fluxbreak*, and the normalization is set by the parameter *norm1* in units of sources per square degree. The fluxes distributed according to the logN–logS distribution are defined over the energy range given by the parameters *bandpasslo* and *bandpasshi* (in keV). The parameters *fluxmin* and *fluxmax* are the minimum and maximum fluxes, in this bandpass, of the logN–logS distributions. The parameter *fluxsens* is the flux threshold defined such that sources fainter than *fluxsens* are treated as "undetected" and their emission subsumed into the diffuse background based on their individual spectra (see below). However, if *fluxsens*=0, the threshold is defined by the optional parameters *ctstoflux* (flux per unit count rate), *sigtonoise* (signal-to-noise ratio), and *exposure* (in seconds) according to *ctstoflux*sigtonoise*sigtonoise*/*exposure* (e.g., a value of *ctstoflux* of 10^{-11} corresponds to a threshold of 2.5×10^{-15} erg cm^{-2} s^{-1} for *sigtonoise*=5 and *exposure*=100 ks). The second logN–logS is a single power-law that may be used to create, for example, a Galactic or an additional extragalactic point source background. The optional parameters *slope2* and *norm2* determine its logN–logS slope, and normalization in sources per square degree. By default, *norm2*=0. The two logN–logS have several parameters in common -- namely *bandpasslo*, *bandpasshi*, *fluxmin*, *fluxmax*, f*luxsens*, *ctstoflux*, *sigtonoise*, and *exposure*.

Spectra for the point sources drawn from the broken power-law logN–logS background are assigned based on the parameter *spectype1*. If *spectype1*=0, the sources are assigned *heasim*-supported spectral models. In this case the model is specified by the *skyback* parameter *specmod1*: plaw (power-law), bbod (blackbod), brem (thermal bremsstrahlung), rs (Raymond-Smith thermal plasma), or mono (mono-energetic); and by the value of the parameter *specpar1* (index for power-law, temperature in keV for blackbody/bremsstrahlung/Raymond-Smith, or line energy in keV for mono-energetic). The foreground column density is given by the parameter *nhmod1*. If *spectype*1=2, the background is given by the "torus" model based on the approach of Ueda et al. 2014 (ApJ, 786, 104). Each source spectrum is determined by one of the torus models from Brightman & Nandra 2011 (MNRAS, 413,1206; BN) with a distinct intrinsic column density and opening angle, and with a randomly selected inclination angle. The opening angle distribution is determined by fractions in five bins (<30, 30-45, 45-60, 60-75, >75) specified by the parameters *fpar0*, *fpar1*, *fpar2*, *fpar3*, and *fpar4*. The intrinsic column density distribution is determined by fractions in six logarithmic N_H bins (<21, 21-22, 22-23, 23-24, 24-25, >25) specified by the parameters *fabs0*, *fabs1*, *fabs2*, *fabs3*, *fabs4*, and *fabs5*. Redshifts are drawn from a distribution assumed to be a simple linear ramp up to z=1, followed by an exponential decline. If s*pectype1*=1, the background is given by the "multi" model based on the approach of Gilli, Comastri, & Hasinger, G. 2007 (A&A, 463, 792) where each point source is an absorbed power-law with index and N_H drawn from two distributions. The power-law index distribution is determined by fractions in five index bins (1.5-1.7, 1.7-1.9, 1.9-2.1, 2.1-2.3, 2.3-2.5) specified by

fpar0, *fpar1*, *fpar2*, *fpar3*, and *fpar4*. Again, the intrinsic column density distribution is determined by fractions in six logarithmic N_H bins (<21, 21-22, 22-23, 23-24, 24-25, >25) specified by *fabs0*, *fabs1*, *fabs2*, *fabs3*, *fabs4*, and *fabs5;* and redshifts assigned as described above. For "multi" models, in the highest N_H-bin the power-law is replaced by a reflection model approximated by a BN torus model with the largest available opening angle, inclination of 0 degrees, the assigned power-law, and the assigned ($>10^{25}$ cm^{-2}) N_H – with the power-law subtracted off. In the next-to-highest N_H-bin the absorbed power-law is supplemented with this same reflection model, scaled down by 0.37 (Gilli et al. 2007).

Spectra for the point sources drawn from the single power-law logN–logS background are assigned in an identical way to those of the broken power-law logN–logS background if *samespec*=YES (i.e., the lists are merged before the spectra are assigned). If *samespec*=NO, the sources are assigned *heasim*-supported spectral models. In this case the model is specified by parameter *specmod2*: plaw (power-law), bbod (blackbod), brem (thermal bremsstrahlung), rs (Raymond-Smith thermal plasma), or mono (mono-energetic). The value of the spectral parameter for this model is specified by *specpar2*, and the foreground column density by the parameter *nhmod2*, as described above for *specmod1* and *nhmod1*.

If *flaglogns* = yes, *slopebright*, *slopefaint1*, *fluxbreak*, *norm1*, *bandpasslo*, *bandpasshi*, *fluxmin*, *fluxmax*, *fluxsens*, and *spectype1* are required and must be set. If *flaglogns* = *no* these are ignored, as are all of the other, optional, parameters associated with the logN–logS component such as those associated with the single power-law logN–logs or with the details of the spectral model.

The *skyback* output may include the following files. (1) A catalog of resolved point sources that includes source positions with spectra specifications. The format follows the *heasim* source definition file for point sources. The name of the output is constructed by appending the value of the parameter *outfileroot* to "pscat". (2) A file that supplements the point source catalog contains values of the redshift and intrinsic absorption. The name of the output is constructed by appending the value of the parameter *outfileroot* to "pszcat". (3) A "catalog" with a single line representing the diffuse emission. The format follows the *heasim* source definition file format for an extended source with a flat distribution. The flat distribution is centered at the position given by the parameters *ra* and *dec*, and covers a circular region extending out to parameter *radius* in arcmin. The name of the output is constructed by appending the value of the parameter *outfileroot* to "difcat". (4) The total diffuse background spectrum corresponding to (3) in the form of a *heasim* user input spectrum ASCII file (flux in photons cm^{-2} s^{-1} $channel^{-1}$ versus energy in keV). The diffuse spectrum is calculated on a user-specified energy grid in keV ranging from the parameter *emin* to the parameter *emax* with a constant grid spacing given by the parameter *de*. For example, one might select emin=0.1, emax=16.0, and de=0.0005 for the Hitomi SXS and emin=0.1, emax=120.0, and de=0.025 for the Hitomi HXI. The name of the output ASCII file is constructed by appending the value of the parameter *outfileroot* to "difspec." (5) An XSPEC table model (FITS) file, with a name constructed by appending the value of the parameter outfileroot to "difspec." This may be directly examined, e.g., via the command "model atable{outfileroot_difspec.fits}" within XSPEC.

4.2 Parameters for skyback

The SKYBACK input parameters as they appear in the parameter file are described below.

outfileroot [string]
The root name used to construct the filenames of the *skyback* outputs. The outputs are: pscat_*outfileroot*.txt, pszcat_*outfileroot.*txt, difcat_*outfileroot.*txt , difspec_*outfileroot.*dat, difspec_*outfileroot.*fits. Required.

ra [double]
The right ascension of the region center to be populated with background (discrete and diffuse) sources. This parameter is given in decimal degrees, J2000 epoch. Required.

dec [double]
The declination of the region center to be populated with background (discrete and diffuse) sources. This parameter is given in decimal degrees, J2000 epoch. Required.

radius [double]
Radius, in arcminutes, of the circular region to be populated with background (discrete and diffuse) sources. Required.

emin [double]
Energy, in keV, of the lower limit of the energy grid for the computed background spectrum. Required.

emax [double]
Energy, in keV, of the upper limit of the energy grid for the computed background spectrum. Required.

de [double]
Constant energy spacing, in keV, of the energy range for the background spectrum. Required.

flaglogns [boolean yes/no]
If yes, the background component originating from point sources drawn from a logN-logS distribution is computed. Optional.

fluxsens[double]
Flux for the point source sensitivity limit used for both logN-logS distributions. Sources with flux above this threshold are treated as discrete point sources, sources below are treated as unresolved and subsumed into the diffuse background. Required, but may be set to 0, in which case the threshold is determined by the *exposure*, *sigtonoise*, and *ctstoflux* parameters. Required if *flaglogns=yes*, otherwise ignored.

fluxmin [double]

Flux lower limit, in erg cm^{-2} s^{-1}, used for both logN-logS distributions. Required if *flaglogns=yes*, otherwise ignored.

fluxmax [double]
Flux upper limit, in erg cm^{-2} s^{-1}, used for both logN-logS distributions. Required if *flaglogns=yes*, otherwise ignored.

bandpasslo [double]
Bandpass lower limit, in keV, over which both logN–logS distributions are defined. Fluxes output in the "pscat_fileroot" file refer to the energy range defined by *bandpasslo* and *bandpasshi*. Required if *flaglogns=yes*, otherwise ignored.

bandpasshi [double]
Bandpass upper limit, in keV, over which both logN–logS distributions are defined. Fluxes output in the "pscat_fileroot" file refer to the energy range defined by *bandpasslo* and *bandpasshi*. Required if *flaglogns=yes*, otherwise ignored.

slopebright1 [double]
Bright-end slope of the first (broken power-law) logN-logS distribution. Required if *flaglogns=yes*, otherwise ignored.

slopefaint1 [double]
Faint-end slope of the first (broken power-law) logN-logS distribution. Required if *flaglogns=yes*, otherwise ignored.

fluxbreak [double]
Flux level, in erg cm^{-2} s^{-1}, where the first (broken power-law) logN-logS distribution changes slope, i.e. slope = *slopebright1* (*slopefaint1*) above (below) *fluxbreak*. Required if *flaglogns=yes*, otherwise ignored.

norm1 [double]
Normalization, in sources/square-degree, of the first (broken power-law) logN-logS distribution. Required if *flaglogns=yes*, otherwise ignored.

spectype1 [integer]
Type of spectral model assigned to the point sources drawn from the first logN-logS distribution (broken power-law) – as well as the second if samespec=YES. The values for spectype1 are 0, 1, 2 with the following meanings. If *spectype1=0,* all sources have identical spectral models as specified in the parameters *specmod1, specpar1,* and *nhmod1*. If *spectype1=1* ("multi"*)*, spectra are absorbed power-laws with column densities and slopes drawn from the distributions specfied in the parameters *fabs0-5* and *fpar0-4*, respectively, with a special treatment in the mildly and fully Compton thick regimes. If *spectype1=2* ("torus"*)*, spectra are Brightman & Nandra torus models with column densities and opening angles drawn from the distributions specified by f*abs0-5* and *fpar0-4*, respectively, and with randomly selected inclination angles. Required if *flaglogns=yes*, otherwise ignored.

specmod1 [string]
Available spectral models that are assigned to the point sources drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. These are: plaw (power-law), bbod (blackbody), brem (thermal bremsstrahlung), rs (Raymond-Smith thermal plasma), or mono (mono-energetic). Optional, ignored if *flaglogns = no*.

specpar1 [double]
Parameter value of the spectral model specified in *specmod1*. The possible parameters are: index (for power-law model), temperature in keV (for blackbody, bremsstrahlung, Raymond-Smith models), or line energy in keV (for mono-energetic model). Optional, ignored if *flaglogns = no*.

nhmod1 [double]
Value for the column density in cm^{-2} used with the spectral model specified in *specmod1*. Optional, ignored if *flaglogns = no*.

fabs0 [double]
Fraction of sources which have assigned $N_H<10^{21}$ cm^{-2} and are drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. This is applicable if spectype1 is either 1 or 2. The value for the fraction ranges between 0-1. Optional, ignored if *flaglogns = no*.

fabs1 [double]
Fraction of sources which have assigned N_H between 10^{21} and 10^{22} cm^{-2} and are drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. This is applicable if spectype1 is either 1 or 2. The fraction values range between 0-1. Optional, ignored if *flaglogns = no.*

fabs2 [double]
Fraction of sources which have assigned N_H between 10^{22} and 10^{23} cm^{-2} and are drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. This is applicable if spectype1 is either 1 or 2. The fraction values range between 0-1. Optional, ignored if *flaglogns = no*.

fabs3 [double]
Fraction of sources which have assigned N_H between 10^{23} and 10^{24} cm^{-2} and are drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. This is applicable if spectype1 is either 1 or 2. The fraction values range between 0-1. Optional, ignored if *flaglogns = no*.

fabs4 [double]
Fraction of sources which have assigned N_H between 10^{24} and 10^{25} cm^{-2} ("mildly Compton thick" regime) and are drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. This is applicable if spectype1 is either 1 or 2. The fraction

values range between 0-1. Optional, ignored if *flaglogns = no*.

fabs5 [double]
Fraction of sources which have assigned $N_H > 10^{25}$ cm^{-2} ("Compton thick" regime) and are drawn from the first logN-logS distribution (broken power-law) – as well as the second if s*amespec*=YES. This is applicable if spectype1 is either 1 or 2. The fraction values ranges between 0-1. Optional, ignored if *flaglogns = no*.

fpar0 [double]
Fraction of sources which have assigned a power law index between 1.5 and 1.7 if *spectype1*=1, or torus opening angles < 30 degrees if *spectype1*=2. Applied to point sources drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. The fraction values ranges between 0-1. Optional, ignored if *flaglogns = no*.

fpar1 [double]
Fraction of sources which have assigned a power law index between 1.7 and 1.9 if *spectype1*=1, or torus opening angles between 30 and 45 degrees if s*pectype1*=2. Applied to point sources drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. The fraction values ranges between 0-1. Optional, ignored if *flaglogns = no*.

fpar2 [double]
Fraction of sources which have assigned a power law index between 1.9 and 2.1 if *spectype1*=1, or torus opening angles between 45 and 60 degrees if *spectype1*=2. Applied to point sources drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. The fraction values ranges between 0-1. Optional, ignored if *flaglogns = no*.

fpar3 [double]
Fraction of sources which have assigned a power law index between 2.1 and 2.3 if *spectype1*=1, or torus opening angles between 60 and 75 degrees if *spectype1*=2. Applied to point sources drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. The fraction values ranges between 0-1. Optional, ignored if *flaglogns = no.*

fpar4 [double]
Fraction of sources which have assigned a power law index between 2.3 and 2.5 if *spectype1*=1, or torus opening angles between 75 and 90 degrees if spectype1=2. Applied to point sources drawn from the first logN-logS distribution (broken power-law) – as well as the second if *samespec*=YES. The fraction values ranges between 0-1. Optional, ignored if *flaglogns = no*.

slope2 [double]
Slope of the second (single power-law) logN-logS distribution. Optional, ignored if *flaglogns = no*.

norm2 [double]
Normalization, in sources/square-degree, of the second (single power-law) logN-logS distribution. Optional, ignored if *flaglogns = no*.

.

samespec [boolean yes/no]
If *samespec*=YES, the spectral model for the point sources from the second logN-logS distribution (single power-law) is assigned in the same way as for the point sources from the first logN-logS distribution (broken power-law), i.e. identical spectra if *spectype1*=0 or spectra drawn from identical spectral parameter distributions if *spectype*=1 or 2. Optional, ignored if *flaglogns = no*.

specmod2 [string]
Available spectral models that are assigned to the point sources drawn from the second logN-logS distribution (broken power-law) if *samespec*=NO. These are: plaw(power-law), bbod (blackbody), brem (thermal bremsstrahlung), rs (Raymond-Smith thermal plasma), or mono (mono-energetic). Optional, ignored if *flaglogns = no*.

specpar2 [double]
Parameter value of the spectral model specified in *spec_mod2*. The possible parameters are: index (for power-law model), temperature in keV (for blackbody, bremsstrahlung, Raymond-Smith models), or line energy in keV (for mono-energetic model). Optional, ignored if *flaglogns = no.*

nhmod2 [double]
Value for the column density in cm^{-2} used with the spectral model specified in *spec_mod2*. Optional, ignored if *flaglogns = no*.

flaggal [boolean yes/no]
If yes, the diffuse background component originating from Galactic halo and Local Hot Bubble hot gas is computed. Optional.

flagswcx [boolean yes/no]
If yes, the background component originating from Solar Wind Charge Exchange is computed. Optional.

swcxOVII [double]
Total flux, in units of LU (1 LU == 1 photon s^{-1} cm^{-2} str^{-1}), of the OVII line complex for the discrete SWCX component. Optional, ignored if *flagswcx = no*.

swcxcont [double]
Total flux, in erg cm^{-2} s^{-1} $arcmin^{-2}$, of the continuous SWCX component. Optional, ignored if *flagswcx = no*.

flagdgrb [boolean yes/no]
NOT IMPLEMENTED. If yes, the diffuse gamma-ray background component is computed. Optional.

flaggrxe [boolean yes/no]

NOT IMPLEMENTED. If yes, the Galactic Ridge background component is computed. Optional.

exposure [double]
Exposure time in seconds used to calculate the point source logN-logS flux threshold (in combination with *sigtonoise* and *ctstoflux*, i.e. as *ctstoflux*sigtonoise*sigtonoise*/*exposure* if an explicit value (*fluxsens*) is not input. The threshold determines which sources are treated as discrete background sources and which as contributing to the diffuse background emission. Optional.

sigtonoise [double]
Minimum signal-to-noise ratio used (in combination with *exposure* and *ctstoflux*) to determine the flux threshold if *fluxsens*=0. Optional.

ctstoflux [double]
Count-rate to flux conversion used (in combination with *sigtonoise* and *ctstoflux*) to determine the flux threshold *ctstoflux*. Optional.

seed [integer]
Random number generator seed. If set to zero, the seed is ignored and the RNG is seeded from the system time. Otherwise it is used as given and consecutive applications with identical seed parameter yields identical output.

clobber [boolean yes/no]:
Overwrites the existing filename if set to yes.

debug [boolean yes/no]:
Diagnostic output is printed on the screen if set to yes.

mode [string]:
Mode to query the parameter file. Acceptable values include: “ql” (query and learn/remember),“hl” (hidden and learn/remember), “q” (query but don't remember), “h” (hidden).

4.3 Default Parameters and Example Run-Script

Using default parameters, *skyback* includes “Galactic” and “Extragalactic” components but no SWCX. The “Extragalactic” component is derived from a broken-power law logN-logS distribution that yields ~100 sources per square-degree above the default threshold of 10^{-14} erg cm^{-2} s^{-1} in the default 0.5–2.0 keV bandpass. By default, these sources are assumed to have identical spectrum, simple unabsorbed power-law models. More realistic models may be set by changing spectype1 from 0 to 1 (“multi”) or 2 (“torus”) and adjusting the distribution with the appropriate parameters. The “run_skyback.sh” script in the ahsimscripts directory utilizes these

default parameters. This script may serve as a template script for user runs; see, also, the additional example in Appendix B.3.

5. Sxsbranch

5.1 Overview

Sxsbranch computes rates and branching ratios for each SXS event grade based on the inputs (file or count rate). These are calculated for each pixel and for the entire array. *Sxsbranch* also statistically estimates the same quantities using the total rates from the input (file or rate) for the entire array using Poisson statistics.

Calculation based on inputs

Sxsbranch operates in three modes: (1) no input file, (2) input simulated file, and (3) input file from observations.

(1) If there is no input file (*infile*=NONE), *sxsbranch* internally simulates events using the *exposure* and *countrate* parameters, with counts distributed in the array according to the file specified by the *pixfrac* parameter. If *pixfrac* = NONE a uniform illumination is assumed. Times are randomly assigned, and event grades assigned accordingly. The branching ratio is calculated using these internally simulated events. There are two different supported timing distributions within the *exposure*: constant count rate profile (*flagburst*=no) and burst-like profile (*flagburst*=yes). To simulate a burst-like lightcurve within the *exposure*, the following parameters also must be set: *ratburst* is the ratio of burst-peak/quiescent count rate; *tburst* gives the burst start time in sec after the beginning of the *exposure*; *trise* is the rise time (assumed linear) in sec; and *tdecay* is the decay time (assumed exponential) in sec. The grades are assigned by comparing the resulting time intervals between events with the time interval values in the parameters *dtmidhigh*, *dtlowmid*, and *dtprimary*: (a) high-resolution events have no preceding or following events within *dtmidhigh*; (b) mid-resolution events have at least one preceding or following event within *dtmidhigh*, but none within *dtlowmid*; (c) low-resolution events at least one preceding or following event within *dtlowmid.* (d) Primary events are defined as having no preceding event within *dtprimary*; (e) secondary events at least one preceding event within *dtprimary*. The outer 20 pixels may be excluded from the branching ratio calculations by setting the parameter pixmask=pixmask.txt.

(2) If the input file is an SXS event file from *heasim* (*infile* set to the filename of the SXS event output file simulated with *heasim* & *filetype*=sim), *sxsbranch* calculates the branching ratio using the simulated SXS file. The simulated files do not have grades assigned by *heasim*. *Sxsbranch* first considers whether events are crosstalking (the option if the parameters *ctphafrac1* and/or *ctphafrac2* are different from zero), and subsequently assigns the grade using the event time and the calculated time intervals to the preceding and following events in the same pixel. The parameters used to calculate crosstalk are *debin, enrgthr, ctphafrac1,* and *ctphafrac2*. These parameters are applied to all pixels. There are two crosstalk types: (a) the first occurs when an event induces crosstalk in the nearest electrical bonded pixel, (b) the second occurs when an

event induces crosstalk in the next-nearest electrical bonded pixel. The first is calculated if *ctphafrac1* is different from 0 and the event has *ctphafrac1**PI > (*enrgthr/debin*). The second is calculated if *ctphafrac2* is different from 0 and the event has *ctphafrac2**PI > (*enrgthr /debin*). The parameters *ctphafrac1/2* define the fraction of crosstalk energy to the original event energy, *enrgthr* is the energy threshold above which crosstalk triggers, and *debin* is the value of the PI bin in eV. The maximum possible crosstalk is induced for the default *enrgthr*=0. The electrical proximity of the pixels is defined by the calibration map pixmap.fits (set by the parameter *ctelpixfile*). Grades are calculated using the *dtmidhigh*, *dtlowmid*, and *dtprimary* parameters as described above. The outer 20 pixels may be excluded from the branching ratio calculations by setting the parameter *pixmask*=pixmask.txt.

(3) If the input SXS event file is from an observation (*infile* set to the SXS event filename from an observation & *filetype*=real), *sxsbranch* calculates the branching ratio using this SXS observation event file. This option may be used after launch since the branching ratio calculation uses the on-board assigned grades. Events are excluded from the branching ratio calculation if: Baseline and lost events are excluded from the branchingratio calculation. The outer 20 pixels may be excluded from the branching ratios calculation by setting the parameter *pixmask*=pixmask.txt.

Calculation based on statistical estimates

For comparison with the grade distribution statistics compiled from real or simulated events, statistical estimates are computed and output. For these, the count rate is distributed on the array according to the file specified by the *pixfrac* parameter. If *pixfrac* = NONE a uniform illumination is assumed. For Pixel 12, the calpixel, the rate is set to the value specified in the *calpixrate* parameter. If ctphafrac1 and/or ctphafrac2 are > 0 crosstalk is calculated assuming that any pixel crosstalks with all of its nearest and/or next-nearest pixels as defined by the electrical proximity calibration map pixmap.fits (set by the parameter *ctelpixfile*). The outer 20 pixels may be excluded from the branching ratios calculation by setting the parameter *pixmask*=pixmask.txt. The fraction of different grades in each pixel is assigned using the *dtmidhigh*, *dtlowmid*, and *dtprimary* parameters as described above, and assuming Poisson statistics.

Option to merge simulated events

Sxsbranch can simulate pileup defined as occurring when events in a given pixel separated by small intervals cannot be distinguished, if the *flagmerge* parameter is set to YES. This is valid either for simulated (*heasim*) event input files, or if *infile*=NONE. In this case, events separated in time by intervals smaller than that given by the *dtmerge* parameter are combined into a single event up to a total time interval given by the *dtmax* parameter. If there is a *heasim* input file, the energy of the merged event is set equal to the sum of energies of the individual events that were merged, and the merge event is discarded if the value exceeds that given by the *maxenergy* parameter. Crosstalk events are added, and events are graded based on the event list after merging.

Supporting files

Sxsbranch uses the following supporting files: (a) pixfrac.txt, (b) pixmap.fits and (c) pixmask.txt. These files are located in the $HEASIM_SUPPORT/hitomi/sxs/sxsbranch/ directory. The pixfrac.txt and pixmask.txt files may are also in $HEADAS/../<machine-architecture>/refdata, while pixmap.fits is generally set to CALDB.
(a) The pixfrac.txt file is used in the statistical estimates, and for simulating events if *infile*=none. The file contains the distribution fraction, for each pixel, of the counts in the total array based on the PSF. The file may be edited to calculate estimates based on different (normalized) distributions.
(b) The pixmap.fits file is used when including crosstalk in calculating branching ratios for *filetype*=sim or *infile*=none, as well as for the associated statistical estimates. The file contains information on the electrical proximity of the pixels necessary to define crosstalk among pixels.
(c) The pixmask.txt file is used to exclude the outer 20 pixels from the calculation when calculating branching ratios, and for the associated statistical estimates. Pixels to be included (excluded) have values of 0 (1) in the file. Different selections of pixels may be chosen by editing this file.

Output

The output of *sxsbranch* is a FITS file with two extensions with identical structure. The first extension, BRANCHEST, contains the results of the statistical estimates based on Poisson statistics. The second extension, BRANCHCALC, contains the results of calculations based on the input data file or count rate. Each extension contains a group of keywords providing the results for the full array and columns providing the results for each pixel. The keywords are listed in Table 7.

Table 7 *Sxsbranch* Header Keywords

Keyword	Value	Comment
BRANCHHP	real	Good events fraction grade HP
BRANCHMP	real	Good events fraction grade MP
BRANCHLP	real	Good events fraction grade LP
BRANCHMS	real	Good events fraction grade MS
BRANCHLS	real	Good events fraction grade LS
RATEHP	real	Good events rate grade HP
RATEMP	real	Good events rate grade MP
RATELP	real	Good events rate grade LP
RATEMS	real	Good events rate grade MS
RATELS	real	Good events rate grade LS
RATEHPCT	real	Crosstalk events rate grade HP
RATEMPCT	real	Crosstalk events rate grade MP
RATELPCT	real	Crosstalk events rate grade LP
RATEMSCT	real	Crosstalk events rate grade MS
RATELSCT	real	Crosstalk events rate grade LS
RATEGOOD	real	Total good events rate all grades
RATECT	real	Total crosstalk events rate all grades
RATEAVG	real	Avg rate per pixel: all events and grades

RATETOT	real	Total rate all events, grades

The total rates are obtained considering the sum of good and crosstalk events. If the file is from an observation, rather than a simulation, the good events do not include any baseline or lost events. If the file is from a simulation, the good events do not include crosstalk.

The output column names and definitions are listed in Table 8.

Table 8 *Sxsbranch* Columns

Column Name	**Format**	**Comment**
PIXEL	1I	Pixel number
CTPIXEL1	1I	First nearest pixel by wiring
CTPIXEL2	1I	Second nearest pixel by wiring
CTPIXEL3	1I	First next-nearest pixel by wiring
CTPIXEL4	1I	Second next-nearest pixel by wiring
RATEGOOD	1E	Good events rate all grades
RATECT	1E	Total crosstalk events rate all grades
RATETOTAL	1E	Total events rate all grades
FRACPSF	1E	Fraction of counts in each pixel
FRACGOOD	1E	Fraction of good events
FRACCT	1E	Fraction of crosstalk events
RATEGOODHP	1E	Good events rate HP grade
RATECTHP	1E	Crosstalk events rate HP grade
RATETOTHP	1E	Total events rate HP grade
RATEGOODMP	1E	Good events rate MP grade
RATECTMP	1E	Crosstalk events rate MP grade
RATETOTMP	1E	Total events rate MP grade
RATEGOODLP	1E	Good events rate LP grade
RATECTLP	1E	Crosstalk events rate LP grade
RATETOTLP	1E	Total events rate LP grade
RATEGOODMS	1E	Good events rate MS grade
RATECTMS	1E	Crosstalk events rate MS grade
RATETOTMS	1E	Total events rate MS grade
RATEGOODLS	1E	Good events rate LS grade
RATECTLS	1E	Crosstalk events rate LS grade
RATETOTLS	1E	Total events rate LS grade
BRANCHHP	1E	Branching ratio HP grade
BRANCHMP	1E	Branching ratio MP grade
BRANCHLP	1E	Branching ratio LP grade
BRANCHMS	1E	Branching ratio MS grade
BRANCHLS	1E	EBranching ratio LS grade

The rates and branching ratios per grade are averages over the entire observation.

If the input file is a simulated file from *heasim*, sxsbranch creates a copy of the input file, adding and filling two columns: PIXEL with the pixel number, and ITYPE with the grade (ITYPE = 0, 1, 2, 3, 4 for HP, MP, MS, LP, LS, respectively). Additionally, if *flagmerge* is YES the PILEUP column in the output events file is set to 1 for merged events and 0 otherwise.

5.2 Parameters for sxsbranch

infile [file name]
Name of the input event FITS file. This file is either the output event file from a *heasim* SXS simulation, or an event file from an observation. Infile may be set to NONE when the branching ratio is calculated using the value input in the parameters *countrate* and *exposure*. If *filetype* is "sim," an an event file with added PIXEL and ITYPE columns is created with this name and ".out" appended.

filetype [string]
Type of the input event file. Values allowed: "sim" if the *infile* is a simulated event file from *heasim;* "real" if the *infile* is from an observation. This parameter is not used if *infile*=NONE.

outfile [file name]
Name of the output *sxsbranch* file with the branching ratio calculation.

countrate [double]
Count rate in count/sec for the entire array. This parameter is only valid if *infile*=NONE.

exposure [double]
Exposure time for the entire array. This parameter is only valid if *infile*=NONE.

pixfrac [string]
Name of the ASCII file with the distribution of the fractional counts in the pixels. The file has two columns. The first contains the SXS Pixel number. The second contains the fraction of counts that fall in each pixel. If set to NONE, the count distribution is uniform in all pixels. This is used for the statistical estimates, and to distribute counts when *infile*=NONE.

pixmask [string]
Name of the ASCII file to exclude pixels in all calculations of the branching ratio. The file has two columns. The first contains the SXS Pixel number. The second is set either to 0 or 1 to include or exclude pixels in the calculation, respectively. If *pixmask* is set to NONE all pixels are included. This parameter is valid for all calculations, as well as for the associated statistical estimates.

ctelpixfile [file]
Name of the FITS file with the SXS electrical pixel map. The file contains the mapping of how the pixels are wired and therefore the pixels that are nearest and next nearest when considering crosstalk. This parameter is set to CALDB by default.

dtprimary [string]
Time in ms. This is used to distinguish primary from secondary events in the grade calculation. The value is set to 69.92 ms and corresponds to the current on-board software setting. It should not be modified.

dtmidhigh [string]
Time in ms. This is used to distinguish high- from mid-resolution events in the grade calculation. The value is set to 69.92 ms and corresponds to the current on-board software setting. It should not be modified.

dtlowmid [string]
Time in ms. This is used to distinguish mid- from low-resolution events in the grade calculation. The value must be < dtmidhigh. The value is set to 17.95 ms and corresponds to the current on-board software setting. It should not be modified.

calpixrate [double]
Count rate in count/sec in the SXS calibration pixel (pixel 12). This parameter is only used for statistical estimates. The default value is 6.0 count/sec.

ctphafrac1 [double]
Energy ratio of the nearest electrically bonded pixels to the original, due to crosstalk. This parameter is used for statistical estimates, and if *infile*=NONE or *filetype* is set to "sim." For the latter, events of energy E are assumed to induce crosstalk in nearest electrically bonded pixels, if *ctphafrac1* * E > *enrgthr*. For the statistical estimate of branching ratios or if *infile*=NONE, this crosstalk is considered if ctphafrac1 > 0, since energy is irrelevant to the procedure.

ctphafrac2 [double]
Energy ratio of the next-nearest electrically bonded pixels to the original, due to crosstalk. This parameter is used for statistical estimates, or if *infile*=NONE or *filetype* is set to "sim". For the latter, events of energy E are assumed to induce crosstalk in next-nearest electrically bonded pixels, if *ctphafrac2* * E > *enrgthr*. For the statistical estimate of branching ratios or if *infile*=NONE, this crosstalk is considered if ctphafrac2 > 0, since energy is irrelevant to the procedure.

debin [double]
Value in eV to convert a PI channel bin to energy. This parameter is only valid if *filetype* is "sim". The conversion of PI to energy is used in the crosstalk calculation. The current value for the output of *heasim* should be set to 1 eV.

enrgthr [double]
Energy threshold, in eV. This parameter is only valid if *filetype* is set to "sim". Events of energy E are assumed to induce crosstalk in adjacent pixels, if *ctphafrac1* * E > *enrgthr*, and next-nearest pixels if *ctphafrac2* * E > *enrgthr*.

flagmerge [boolean yes/no]
Flag to merge events separated in time by intervals smaller than that given by the *dtmerge* parameter. This parameter is valid if *infile*=NONE or if *filetype* is "sim." Consecutive events separated in time by less than *dtmerge* in a given pixel are combined into a single event up to a total time interval given by the *dtmax* parameter, and discarded if the sum of their energies exceeds the value given by the *maxenergy* parameter. Crosstalk events are added, and events are

graded based on the event list after merging. If *filetype* is "sim," the PILEUP column in the output events file is set to 1 for such merged events and 0 otherwise.

dtmerge [double]
Time interval, in ms, within which consecutive events are merged. This parameter is valid if *infile*=NONE or if *filetype* is "sim," and *flagmerge=YES.* Must be less than dtlowmid.

dtmax [double]
Maximum time, in ms, within which consecutive events are merged. This parameter is valid if *infile*=NONE or if *filetype* is "sim", and *flagmerge*=YES. If events arrive separated in time by less than the interval defined by dtmerge, dtmax defines the maximum total time interval within which events are merged.

maxenergy [double]
Maximum energy, in keV, for merged events. Merged events created from events with total summed energy greater than this are discarded. This parameter is valid if *infile*=NONE or if *filetype* is "sim," and *flagmerge=YES.*

flagburst [boolean yes/no]
Flag to distribute the count rate as a burst-like lightcurve. This parameter is only valid for *infile=NONE*. If set to YES, event times are distributed as a burst profile lightcurve defined by the parameters *ratburst, tburst, trise,* and *tdecay*. If set to NO, the count distribution is uniform within the *exposure*.

ratburst [double]
Ratio of the burst peak rate to the quiescent rate. This parameter is only valid if *infile=NONE* and *flagburst=YES*.

tburst [double]
Start time of the burst in sec after the beginning of the exposure. This parameter is only valid if *infile=NONE* and *flagburst=YES*.

trise [double]
Rise time in sec for the burst profile. The rise time is assumed to be linear. This parameter is only valid if *infile=NONE* and *flagburst=YES*.

tdecay [double]
Decay time in sec for the burst profile. The decay time is assumed exponential. This parameter is only valid if *infile=NONE* and *flagburst=YES*.

tstart [double]
Time since 2014 [s] to use for CALDB query if infile is set to NONE.

seed [integer]

.

Random number generator seed. If set to zero, the *seed* is ignored and the RNG is seeded from the system time. Otherwise it is used as given and consecutive applications with identical *seed* parameter yields identical output.

buffer [integer]
Rows to buffer (-1=auto, 0=none, >0=numrows).

clobber [boolean yes/no]:
Overwrites existing file if set to yes.

chatter [integer]
Chatter level for output. Value 0-3 with 1 minimum chatter, 3 maximum chatter.

logfile [string]
Name of log file. The log file is named with the task name if *logfile* is set to DEFAULT. To clobber an existing file, use '!' and NONE for no logfile.

debug [boolean yes/no]:
Diagnostic output is printed on the screen if set to yes.

history [boolean yes/no]:
Record tool parameters in HISTORY keywords in the output FITS file, if set to yes.

mode [string]:
Mode to query the parameter file. Acceptable values include: "ql" (query and learn/remember), "hl" (hidden and learn/remember), "q" (query but don't remember), "h" (hidden).

Appendix A Test Data Details

Examples of source defintion files and user spectra are contained under the ahsimfiles/testdata directory (see, also, heasimfiles/testdata/source_data/heasim_source_header.txt -- the source defintion file header file -- for additional details).

A.1 Source Definition Files

The $HEASIM_SUPPORT/testdata/source_data directory contains the following examples of source defintion files:

(1) *point_input.dat*: a single point-source with a 0.5 keV blackbody spectrum:
81.5,-69.5,1.0E+21,blac,0.5,1.0e-11,2.0-10.0,none,2,2
(2) *point_pulsed_input.dat*: a single pulsed point-source with a power-law spectrum:
81.5,-69.5,1.0E+21,pow,0.5,1.0e-11,2.0-10.0,none,2,2,pulse(1000.0,0.5)
(3) *point_userspec_input.dat*: a single point-source with a user-supplied input spectrum in XSPEC format:

81.5,-69.5,1.0E+21,user,0.0,0.0,0.0-0.0,myspec.txt,2,2

(4) *point_multi_input.dat*: multiple point sources with different spectra:

81.5,-69.5,1.0E+21,user,0.0,0.0,0.0-0.0,myspec1.txt,2,2
81.7,-69.5,1.0E+21,user,0.0,0.0,0.0-0.0,myspec2.txt,2,2
81.5,-69.9,1.0E+21,user,0.0,0.0,0.0-0.0,myspec3.txt,2,2

(5) *beta_input.dat*: a one-arcminute core radius elliptical (axial ratio of 0.5) beta-model distribution w/ rotation angle and uniform spectrum given by a user-supplied input spectrum in "SHERPA" format:

81.5,-69.5,1.0E+21,user,0.0,0.0,0.0-0.0,myspec.txt,1,1,extmod(beta,0.7,1.0,0.5,45.0,0.0,10.0)

(6) *vbeta_input.dat*: a one-arcminute core radius elliptical beta-model distribution w/ temperature profile:

81.5,-69.5,1.0E+21,rs,1.0,3.0e-12,0.5-10.0,none,2,2,extmod(beta,0.7,1.0,1.0,0.0,0.0,2.0)
81.5 ,-69.5,1.0E+21,rs,2.0,5.0e-12,0.5-10.0,none,2,2,extmod(beta,0.7,1.0,1.0,0.0,2.0,4.0)
81.5,-69.5,1.0E+21,rs,4.0,4.0e-12,0.5-10.0,none,2,2,extmod(beta,0.7,1.0,1.0,0.0,4.0,6.0)
81.5,-69.5,1.0E+21,rs,5.0,6.0e-12,0.5-10.0,none,2,2,extmod(beta,0.7,1.0,1.0,0.0,6.0,10.0)

(7) *flat_input.dat*: a flat distribution ranging from 0-20' with a user-supplied input spectrum in XSPEC format:

81.5,-69.5,1.0E+21,user,0.0,0.0,0.0-0.0,myspec.txt,2,2,extmod(flat,0.0,20.0)

(8) *image_input.dat*: an image with a 5 keV brems spectrum:

81.5,-69.5,1.0E+21,brem,5.0,3.0e-11,2.0-10.0,none,2,2,image(chandra_image.fits,0,0,0,0)

(9) *subimage_input.dat*: a subimage with a 1.5 keV monoenergetic spectrum:

81.5,-69.5,1.0E+21,mono,1.5,3.0e-11,2.0-10.0,none,2,2, /
image(chandra_image.fits,430,600,430,600)

(10) *ellip_input.dat*: an elliptical ring (axial ratio of 0.5) w/ rotation angle and spectrum given by a user-supplied input spectrum in "SHERPA" format:

81.5,-69.5,1.0E+21,user,0.0,0.0,0.0-0.0,myspec.txt,1,1,extmod(ellipse,0.5,45.0,2.0,5.0)

(11) *power_input.dat*: a power-law distribution with a Raymond-Smith spectrum:

81.5,-69.5,1.0E+21,rs,0.5,3.0e-11,0.5-2.0,none,2,2,extmod(power,1.5,0.0,100.0)

(12) *gauss_input.dat*: a gaussian distribution with a user-supplied input spectrum in XSPEC format:

81.5,-69.5,1.0E+21,user,0.0,0.0,0.0-0.0,myspec.txt,2,2,extmod(gauss,0.5,0.5,0.0)

A.2 Spectral Test Files

The $HEASIM_SUPPORT/testdata/user_spectra subdirectory includes the following user input spectrum files spanning the energy scales of the Astro-H instruments indicated in the file name. All are user-file format-flag=2, except sxs_rs_1.0keV_flux10.0_band0.2_12_sherpa.dat is user-file format-flag=1. The file sxs_rs_1.0keV_flux10.0_band0.2_12_sherpa.dat has units=1, the files called XXX_wave.dat have units=3, and the rest have user-spectrum units=2.

0.5 keV blackbody, 0.2-12 keV flux = 1e-11 erg/cm2/sec --
hxi_bbody_0.5keV_flux1.0_band0.2_12.dat

Multiple emission lines, each with flux 6.2416e-03 photons/cm2/sec --
hxi_lines.dat
sxi_lines.dat

sxs_lines.dat
sxs_lines_wave.dat
Power-law, index 1.4, 0.2-12 keV flux = 2-10 keV flux = 4.6e-11 erg/cm2/sec --
hxi_pow_slope1.4_flux4.6_band2_10.dat
sxi_pow_slope1.4_flux4.6_band2_10.dat
sxi_pow_slope1.4_flux4.6_band2_10_wave.dat
sxs_pow_slope1.4_flux4.6_band2_10.dat
Power-law, index 1.4, NH=1e22, 0.2-12 keV flux = 2-10 keV flux = 4.6e-11 erg/cm2/sec ---
sxs_pow_slope1.4_abs1e22_flux4.6_band2_10.dat
5.0 kev brems, 2-10 keV flux = 1e-11 erg/cm2/sec --
sxi_brem_5keV_flux1.0_band2_10.dat
1.0 kev Raymond-Smith, 0.2-12 keV flux = 1e-10 erg/cm2/sec --
sxs_rs_1.0keV_flux10.0_band0.2_12.dat
sxs_rs_1.0keV_flux10.0_band0.2_12_sherpa.dat
1.0 kev Raymond-Smith, NH=1e21, 0.2-12 keV flux = 1e-10 erg/cm2/sec --
sxs_rs_1.0keV_abs1e21_flux10.0_band0.2_12.dat

Appendix B Examples for XARM

This appendix contains examples for XARM calorimeter simulation (see also section 3.6 for the support files). There are two examples the first simulates a spectrum using only XSPEC, and example 2 uses both XSPEC and '*heasim*'.
Many other examples of simulations for the SXS are in the Appendix C. To replicate those examples is sufficient to change in the scripts, described in the Appendix C, the supporting files (as for rmf, arf, vig, psf, inst) with those relevant to XARM and listed in Table 5 as well as the mission name from mission="astro-h" to mission="hitomi" . This is explained in the Example 3.

B.1 XSPEC simulation for a point source

This example shows how to simulate a spectrum using XSPEC and can be used if no spatial information about the simulated photons needs to be retained.
The example simulation is for a point source with an absorbed power-law spectrum and relativistically broadened Fe Ka emission line. No background is included in the simulation. The model to be simulated within XSPEC is the following:

wa*(zpo + laor), with the following parameters:

2-10 keV flux = 3×10^{-11} erg cm^{-2} s^{-1}
z = 0.02
Exposure time = 100 ks
Gamma (power-law photon index) = 1.8
Column density $N_H = 1\times 10^{21}$ cm^{-2}
Emission line using the "laor" model in XSPEC, with:
Line rest energy = 6.4 keV
Emissivity index q = 2.5

.

Equivalent width (EW) = 300 eV
Inner radius = 1.235 Rg
Outer radius = 400 Rg

- Step 1 Make a working directory, e.g.

```
mkdir work
```

Go into the work/ directory and for convenience copy the following files:

```
cd work
cp $HEASIM_SUPPORT/hitomi/sxs/response/*.rmf .
cp $HEASIM_SUPPORT/hitomi/sxs/response/*.arf .
cp $HEASIM_SUPPORT/hitomi/sxs/background/*.pha
cp $HEASIM_SUPPORT/../heasimscripts/*.xcm .
cp $HEASIM_SUPPORT/../heaimscripts/*.pha .
```

- Step 2 Start up Xspec and read in dummy spectrum with the *data* command and set up the initial XSPEC model with the *model* command

```
> xspec
           XSPEC version: 12.9.1
    Build Date/Time: Wed May 10 12:25:09 2017

XSPEC12>
XSPEC12>data dummy.pha
XSPEC12>mo wa*(zpo + laor)

Input parameter value, delta, min, bot, top, and max values for ...
              1      0.001(      0.01)          0          0     100000      1e+06
1:wabs:nH>0.1
              1       0.01(      0.01)         -3         -2          9         10
2:zpowerlw:PhoIndex>1.8
              0      -0.01(      0.01)     -0.999     -0.999         10         10
3:zpowerlw:Redshift>0.02
              1       0.01(      0.01)          0          0      1e+20      1e+24
4:zpowerlw:norm>
            6.4       0.05(     0.064)          0          0        100        100
5:laor:lineE>
              3       -0.1(      0.03)        -10        -10         10         10
6:laor:Index>2.5
          1.235       -0.1(   0.01235)      1.235      1.235        400        400
7:laor:Rin_G>
            400       -0.1(         4)      1.235      1.235        400        400
8:laor:Rout_G>
             30         -1(       0.3)          0          0         90         90
9:laor:Incl>40
              1       0.01(      0.01)          0          0      1e+20      1e+24
10:laor:norm>0.01

========================================================================
Model wabs<1>(zpowerlw<2> + laor<3>) Source No.: 1   Active/Off
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   wabs       nH         10^22    0.100000     +/-  0.0
   2    2   zpowerlw   PhoIndex            1.80000      +/-  0.0
   3    2   zpowerlw   Redshift            2.00000E-02  frozen
   4    2   zpowerlw   norm                1.00000      +/-  0.0
   5    3   laor       lineE      keV      6.40000      +/-  0.0
   6    3   laor       Index               2.50000      frozen
   7    3   laor       Rin_G               1.23500      frozen
```

```
 8    3   laor       Rout_G              400.000      frozen
 9    3   laor       Incl       deg      40.0000      frozen
10    3   laor       nor                 1.00000E-02   +/-   0.0
_____________________________________________________________________

XSPEC12>
```

The initial normalizations of the continuum and line above are trials which must be adjusted to give the desired 2-10 keV flux and line EW. First find the EW of the line:

```
XSPEC12>eqw 3
Data group number: 1
Additive group equiv width for Component 3:  0.314782 keV
```

To obtain an EW=300 eV, the line normalization should be 0.01*(300/314.78) = 9.55e-3. Change the 'laor' model normalization with the command *newpar*

```
XSPEC12>newp 10 9.55e-3
```

Calculate the 2-10 keV flux with the trial normalization:

```
XSPEC>flux 2 10
Model Flux   0.50431 photons (3.4304e-09 ergs/cm^2/s) range (2.0000 - 10.000 keV)
```

To obtain the 2-10 flux = 3.00×10^{-11} erg cm^{-2} s^{-1}, the correction factor is (3.00/343.04), which must be applied to both the power-law normalization and the adjusted line flux:

power-law normalization = 1.0*(3.00/343.04) = 8.75e-3
line normalization = 9.55e-3*(300/343.04)=8.35e-5

Change both normalizations with the command *newpar*

```
XSPEC>newp 10 8.35e-5
XSPEC>newp 4 8.75e-3
```

Check that the normalization are applied with the command *show all*

```
XSPEC12>show all
=========================================================================
Model wabs<1>(zpowerlw<2> + laor<3>) Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   wabs       nH         10^22    0.100000     +/-  0.0
   2    2   zpowerlw   PhoIndex             1.80000      +/-  0.0
   3    2   zpowerlw   Redshift             2.00000E-02  frozen
   4    2   zpowerlw   norm                 8.75000E-03  +/-  0.0
   5    3   laor       lineE      keV       6.40000      +/-  0.0
   6    3   laor       Index                2.50000      frozen
   7    3   laor       Rin_G                1.23500      frozen
   8    3   laor       Rout_G               400.000      frozen
   9    3   laor       Incl       deg       40.0000      frozen
  10    3   laor       norm                 8.35000E-05  +/-  0.0
_____________________________________________________________________


XSPEC12>eqw 3
Data group number: 1
Additive group equiv width for Component 3:  0.300392 keV
```

.

```
XSPEC12>flux 2 10
Model Flux 0.0044126 photons (3.0015e-11 ergs/cm^2/s) range (2.0000 - 10.000 keV)
```

- Step 3: Using this model, make a fake spectrum with exposure time 100 ks (using the H, 5 eV resolution rmf):

```
XSPEC12>fakeit none
For fake spectrum #1 response file is needed: xarm_res_h5ev_20170818.rmf
   ...and ancillary file: xarm_res_pnt_fa_20170818.arf
 Use counting statistics in creating fake data? (y):
 Input optional fake file prefix:
 Fake data file name (spec.fak): ptsrc_model1_sxs_t100ks.fak
 Exposure time, correction norm, bkg exposure time (1.00000, 1.00000, 1.00000): 100000.

No background will be applied to fake spectrum #1
```

This makes the fake spectrum ptsrc_model1_sxs_t100ks.fak, which is now already loaded into XSPEC with the specified RMF and ARF, and can be fitted with models just as a real spectrum would be. Fig. 1 shows plots of the simulated counts and photon spectra, overlaid with the input model.

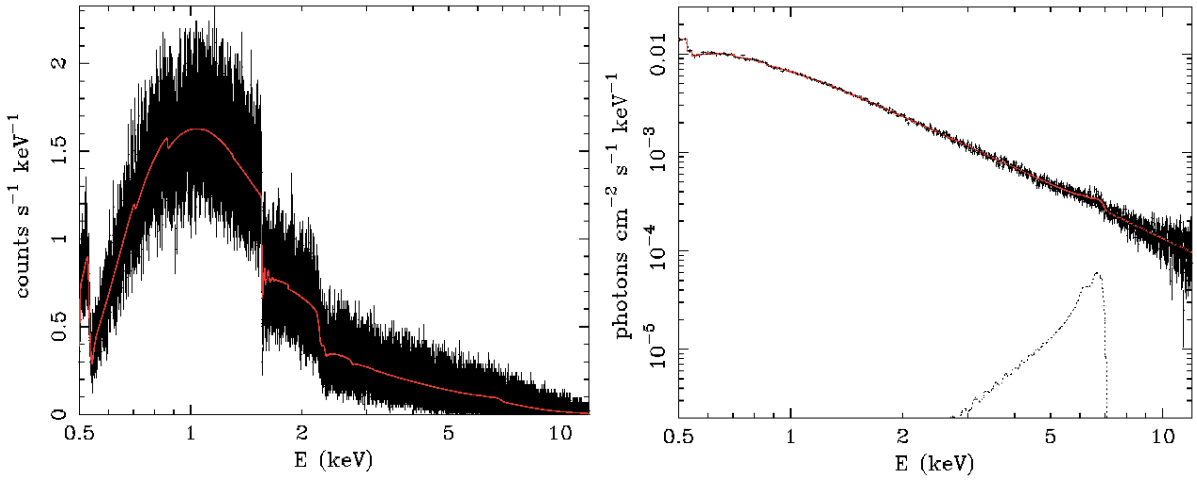


Figure 1:Left: counts spectrum for simulation in example 1. Right: Binned photon spectrum for simulation in example 1.

Since the number of counts per bin may be small, before starting the fitting change the statistic to the C-statistic with the command *statistic*

```
XSPEC12>statistic cstat
```

B.2 Simulation for an extended source

This example shows how to use *heasim* to simulate an event list and how to extract a spectrum with *xselect.* The calorimeter array consists of 6x6 pixel detector array with 35 active pixels and one calibration pixel with a field of view of about 3arcmins.

The example is a simulation of an extended source with a beta-model spatial distribution and a single-temperature optically-thin thermal spectrum with velocity broadening. The spectral model to input in the *heasim* source definition file is complex. One way is to simulate the model within XSPEC and create an ascii file of the model first (a) and import the ascii model in the source definition file for *heasim* after (b). The model to be simulated within XSPEC is the following:

XSPEC model: Tbabs*bvvapec,
z=0.0174807
kT= 3.92586 keV
Velocity (sigma) = 175.237 km/s
$N_H = 1.38 \times 10^{21}$ cm^{-2}
Relative element abundances as in bbvapec_model_example.xcm.

The details of the spatial model are:
$\beta = 0.53$; core radius = 1.26 arcmin, maximum radius = 5.7 arcmin.

For convenience this model is provided within the heasimscripts/ directory and named bbvapec_model_example.xcm.
NOTE : To create this model the user have to have access to the XSPEC model tables. The path to the location of XSPEC model tables is set when the software is installed and the user should have defined the environment variable $HEADAS.

- Step 1 Make a working directory, e.g.

```
mkdir work
```

Go into the work/ directory and for convenience copy the following files:

```
cd work
cp $HEASIM_SUPPORT/hitomi/sxs/response/*.rmf .
cp $HEASIM_SUPPORT/hitomi/sxs/response/*.arf .
cp $HEASIM_SUPPORT/hitomi/sxs/background/*.pha
cp $HEASIM_SUPPORT/../heasimscripts/*.xcm .
cp $HEASIM_SUPPORT/../heaimscripts/*.pha .
```

- Step 2. Start up XSPEC, set up the location of the thermal model table and atomic database with the *xset* command, import the model file bbvapec_model_example.xcm, fake the spectrum with the *fake* command and save the fake spectrum in an ascii file.

```
> xspec
        XSPEC version: 12.9.1
  Build Date/Time: Wed May 10 12:25:09 2017

XSPEC12>
XSPEC12>xset APECROOT <path>/../spectral/modelData/apec_v3.0.7
XSPEC12>@bbvapec_model_example.xcm
```

Check the model has been imported correctly using the *show all* command

```
XSPEC12>show all
========================================================================
Model TBabs<1>*bvvapec<2> Source No.: 1   Active/On
```

.

```
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   TBabs      nH         10^22    0.138000     +/-  0.0
   2    2   bvvapec    kT         keV      3.92586      +/-  0.0
   3    2   bvvapec    H                   1.00000      frozen
   4    2   bvvapec    He                  1.00000      frozen
   5    2   bvvapec    Li                  1.00000      frozen
   6    2   bvvapec    Be                  1.00000      frozen
   7    2   bvvapec    B                   1.00000      frozen
   8    2   bvvapec    C                   1.00000      frozen
   9    2   bvvapec    N                   1.00000      frozen
  10    2   bvvapec    O                   1.00000      frozen
  11    2   bvvapec    F                   1.00000      frozen
  12    2   bvvapec    Ne                  1.00000      frozen
  13    2   bvvapec    Na                  1.00000      frozen
  14    2   bvvapec    Mg                  1.00000      frozen
  15    2   bvvapec    Al                  1.00000      frozen
  16    2   bvvapec    Si                  0.636265     +/-  0.0
  17    2   bvvapec    P                   0.687949     = p18
  18    2   bvvapec    S                   0.687949     +/-  0.0
  19    2   bvvapec    Cl                  0.702005     = p20
  18    2   bvvapec    S                   0.687949     +/-  0.0
  19    2   bvvapec    Cl                  0.702005     = p20
  20    2   bvvapec    Ar                  0.702005     +/-  0.0
  21    2   bvvapec    K                   0.702005     = p20
  22    2   bvvapec    Ca                  0.716875     +/-  0.0
  23    2   bvvapec    Sc                  0.634338     = p28
  24    2   bvvapec    Ti                  0.634338     = p28
  25    2   bvvapec    V                   0.634338     = p28
  26    2   bvvapec    Cr                  0.969799     +/-  0.0
  27    2   bvvapec    Mn                  0.903732     +/-  0.0
  28    2   bvvapec    Fe                  0.634338     +/-  0.0
  29    2   bvvapec    Co                  0.634338     = p28
  30    2   bvvapec    Ni                  0.655827     +/-  0.0
  31    2   bvvapec    Cu                  0.634338     = p28
  32    2   bvvapec    Zn                  0.634338     = p28
  33    2   bvvapec    Redshift            1.74807E-02  +/-  0.0
  34    2   bvvapec    Velocity   km/s     175.237      +/-  0.0
  35    2   bvvapec    norm                0.160711     +/-  0.0
_____________________________________________________________________________
```

Create a fake spectrum with an exposure time of 100 ks:

```
XSPEC12>fakeit none

For fake spectrum #1 response file is needed: xarm_res_h5ev_20170818.rmf
   ...and ancillary file: xarm_res_bet_fa_20170818.arf
 Use counting statistics in creating fake data? (y):
 Input optional fake file prefix:
 Fake data file name (spec.fak): bvvapec_betamod_model1_sxs_t100ks.fak
 Exposure time, correction norm, bkg exposure time (1.00000, 1.00000, 1.00000): 100000.

No background will be applied to fake spectrum #1
```

This creates a fake spectrum called bvvapec_betamod_model1_sxs_t100ks.fak, which is now already loaded into XSPEC. The arf were calculated for the beta model with the parameters $\beta = 0.53$; core radius = 1.26 arcmin, maximum radius = 5.7 arcmin.

Fig. 2 shows a plot of the simulated counts spectrum overlaid with the input model.

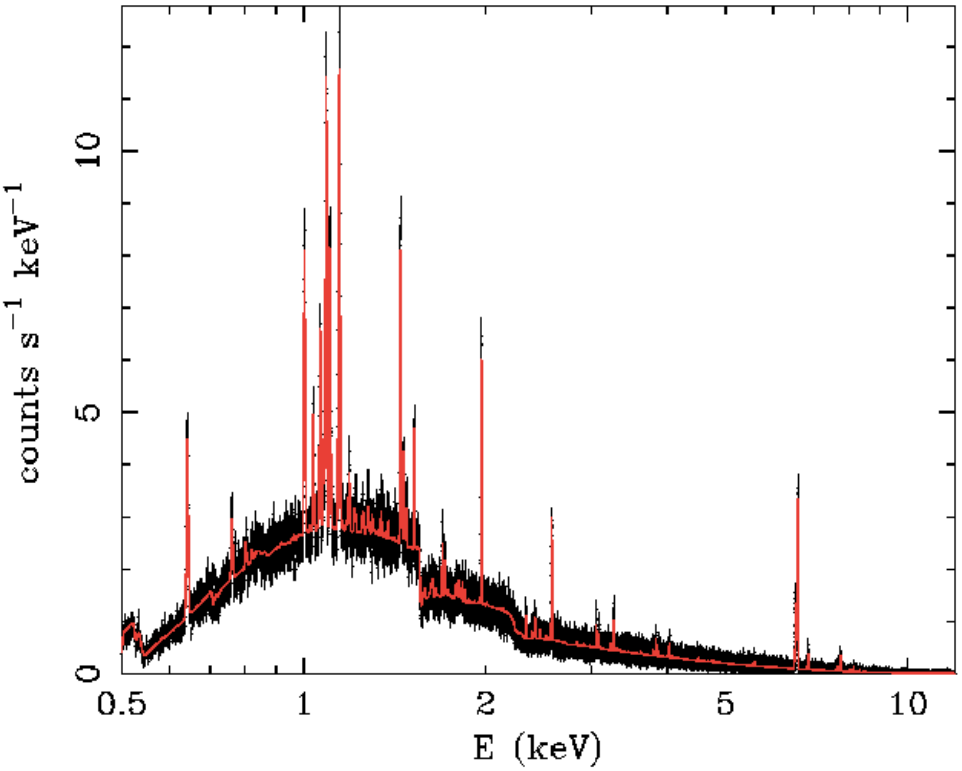


Figure 2: Counts spectrum corresponding to the XSPEC simulation in example 2, of an optically-thin thermal plasma.

The 2-10 keV flux for this model is 1.346×10^{-10} erg cm^{-2} s^{-1}, which can be found using the flux command:

```
XSPEC12>flux 2 10
 Model Flux   0.02177 photons (1.3463e-10 ergs/cm^2/s) range (2.0000 - 10.000 keV)
```

Note: This flux is for the entire model region, a circle with radius 5.7 arcmin, much larger than the size of the detector. To adjust the model flux, the normalization of the *bvvapec* component should be changed in proportion to the desired flux (parameter 35 in the XSPEC model).

To save the model in an ascii file to be used by *heasim* use the following commands:

```
XSPEC12>ipl model
PLT>wenv bvvapec_model
PLT>exit
XSPEC12>
```

The model is saved in the file bvvapec_model.qdp

- Step 2: Create the source definition file, heasim_sourcedef.dat, for *heasim* to contain the following line :

```
49.95,41.51,0.0,user,0.,0.,0.-0.,bvvapec_model.qdp,2,2,extmod(beta,0.53,1.26,1.0,0.0,0.0,5.7)
```

The first two numbers are the RA and DEC coordinates of the source and the model is provided with the ascii file ceated in Step 1 (see *Source definition file* section of this guide for the meaning of all other paramaters).

- Step 3: Set up the HEASIM environment variable to run *heasim* and XSELECT :

```
setenv HEASIM_SUPPORT <path to heasimfiles directory>
setenv XSELECT_MDB $HEASIM_SUPPORT/auxiliary/xselect.mdb.heasim
```

Run *heasim* with the command:

```
heasim mission=hitomi instrume=SXS rapoint=49.95 decpoint=41.51 roll=0.00 exposure=100000.0
flagsubex=no         insrcdeffile=heasim_sourcedef.dat         outfile=heasim_events_betmod1.fits
psffile=$HEASIM_SUPPORT/hitomi/sxs/psf/sxs_psfimage_20140618.fits                    vigfile=NONE
rmffile=xarm_res_h5ev_20170818.rmf      arffile=xarm_res_bet_pa_20170818.arf      arfrmftol=1.0e0
intbackfile=none  psbackfile=none  difbackfile=none  pszbackfile=none  resample=yes  skipfov=no
dtpileup=0.0    getinfile=no    debug=no    clobber=yes    mode=ql    mdbfile=$LHEA_DATA/heasim.mdb
seed=99923112

Running HEASim, v. 2017-05-05


 Input Calibration files
   intbackfile  = none
   psffile                                                                                  =
/XARM/xarm/proposal/release_20170915/arfs_for_roses/ahsimfiles/hitomi/sxs/psf/sxs_psfimage_201406
18.fits
   vigfile      = none
   arffile      = xarm_res_bet_pa_20170818.arf
   rmffile      = xarm_res_h5ev_20170818.rmf

 Global simulation info
   Pointing Direction (RA, DEC, ROLL): 49.950000, 41.510000, 0.000000
   Exposure Time (s): 100000.000000
   Mission:           hitomi
   Instrument:        SXS
   dtpileup:          0.000000
   flagsubex:         0
   subexposure:       0.000000
   resample:          1
   skipfov:           0

 Debugging mode: Disengaged

 Using user input seed = 99923112

Reading     mission     database     file     /software/headas/release/x86_64-unknown-linux-gnu-
libc2.17/refdata/heasim.mdb ...
...done.

Reading instrument map file...
...done.

All calibration files located successfully.

Confirmed that supplied ARF file is a valid ARF file.
Legacy HEASP reading ARF file into arf_struct.......done.

Confirmed that supplied RMF file is a valid RMF file.
Legacy HEASP reading RMF file into rmf_struct.......done.

nebin=32768 nebin_rmf=32768
```

```
rmffile!=none
***** ebin_lo[0]==0
Checking ARF/RMF compatibility...
ARF/RMF compatibiilty check passed successfully.

Nonzero RMF Energy Sensitivity: 0.000250 - 16.383750 keV.

Reading input file...
Found 1 valid sources in file heasim_sourcedef.dat
sformat = 2
...done.

Checking if sources fall within hitomi SXS detector (set debug=yes for more detail)...
Pointing:  RA = 49.950000   Dec = 41.510000

Initializing output FITS file...
...done.

...done.
Reading PSF file...
   Reading image 0...
   Reading image 1...
   Reading image 2...
   Reading image 3...
...done.

Initializing Xspec models:
 Solar Abundance Vector set to angr:  Anders E. & Grevesse N. Geochimica et Cosmochimica Acta 53,
197 (1989)
 Cross Section Table set to bcmc:  Balucinska-Church and McCammon, 1998
Done initializing Xspec models.

Will simulate exposures such that:
  1 sub-exposures of 100000s

Processing 1 sources (set "debug=yes" for more detail)...

  Processing source: 0


...done processing sources.


Removed 0 total (source+background) events that exceeded the PI channel array.

Final number of:
               source events =     485675
          background events =          0
         ------------------------------------
                total events =     485675

Deallocating bin data...
...done.
Deallocating source data...
...done.
Deallocating source data...
...done.
Deallocating RMF data...
...done.
Deallocating ARF data...
...done.
Deallocating psf data...
...done.

Heasim finished with no errors, output file: heasim_events_betmod1.fits
```

The output simulation event file is heasim_events_betmod1.fits.

Note that the ARF used with *heasim* is different to the one used to simulate the spectrum in XSPEC (step 1). This is because *heasim* requires the ARF for no region selection whereas the ARF for XSPEC corresponds to a region covering the detector only.

- Step 4 : Extract a spectrum using XSELECT . Read in XSELECT the event file created by *heasim* with the command *read event file* and extract and save the spectrum in XSELECT with the command *extract spectrum* and *save spectrum file*.

```
 > xselect
                **  XSELECT V2.4d  **

> Enter session name >[xsel]
xsel:SUZAKU > read eve heasim_events_betmod1.fits .
Got new mission: HITOMI
> Reset the mission ? >[yes]

 Notes: XSELECT set up for      HITOMI
 Time keyword is TIME       in units of s
 Default timing binsize =   16.000

Setting...
 Image  keywords   = X          Y           with binning =    1
 Energy keyword   = PI                     with binning =    1

Getting Min and Max for Energy Column...
Got min and max for PI:     0  32767

could not get minimum time resolution of the data read
MJDREF =  5.7988895914000E+04 with TIMESYS = TT
 Number of files read in:            1


    OBJECT      TELESCOP    INSTRUME    DETNAM      DATAMODE    DATE-OBS            DATE-END
      1 NOT_FOUND   HITOMI      SXS         NOT_FOUND   STANDARD    2017-08-23T21:30:07 2017-08-
25T01:16:47

xsel:HITOMI-SXS-PX_NORMAL > extr spectrum
extractor v5.32    15 Feb 2017
 Getting FITS WCS Keywords
 Doing file: /XARM/xarm/proposal/release_20170915/arfs_for_roses/work3/heasim_events_betmod1.fits
100% completed
          Total      Good    Bad: Time     Phase     Grade       Cut
         485675    485675            0         0         0         0
================================================================================
    Grand Total      Good    Bad: Time     Phase     Grade       Cut
         485675    485675            0         0         0         0
   in 9.99998E+04 seconds
 Spectrum         has   485675 counts for  4.857     counts/sec
 ... written the PHA data Extension

xsel:HITOMI-SXS-PX_NORMAL > save spectrum heasim_events_betmod1.pha
```

This creates the spectrum heasim_events_betmod1.pha. It can be read into XSPEC and fitted with a model. The ARF that should be used for this is the one used in step 1 (xarm_res_bet_fa_20170818.arf) since the spectrum is extracted from the detector region only.
The spectrum made directly by XSPEC in step 2 has a flux different by ~10%. with the spectrum made from the *heasim* events file. This is because the PSF used by *heasim* is for a point source and is based on ground measurements, and the vignetting in the *heasim* spectrum is averaged over the extended source region. Instead the spectrum simulated directly within XSPEC uses

only the ARF generated using the in-flight calibration with a beta model for extened sources. In the case of a point-source with simple power-law spectrum, the difference is only ~2%. In general, the differences in flux between the spectra simulated by XSPEC and heasim depend on the spatial distribution and the exact spectral model and on the statistics.

B.3 Simulation using the existing scripts

This example shows how to change and use one of the existing scripts for Astro-H described in appendix C1 for XARM. The script is located in the heasimscripts/ directory and named

alldetectors.sh

and simulate a 10 ks observation for a point source on axis with an absorbed power-law spectrum and with 0 roll angle.

Rename the alldetectors.sh with a new name.

```
cp alldetectors.sh sim_c1_sxsonly.sh
```

Edit sim_c1_sxsonly.sh and remove all lines starting from `instrument ="sxi"` and change the support_dir, mission arf rmf and back parameters to use the files in the heasimfiles under the directory hitomi/. The final modified script should look as:

```
#! bin/sh

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

supp_dir="hitomi"                                    # support subdirectory
mission="hitomi"                                      # mission
instrume="sxs"                                        # instrument
cal_dir="sxs"                                       # master calibration data directory
resp_dir=$HEASIM_SUPPORT/$supp_dir/$cal_dir/response    # response directory
psf_dir=$HEASIM_SUPPORT/$supp_dir/$cal_dir/psf          # psf directory
vig_dir=$HEASIM_SUPPORT/$supp_dir/$cal_dir/vignette     # vignette directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data   # directory containing source files
back_dir=$HEASIM_SUPPORT/$supp_dir/$cal_dir/background  # int-bkg directory

arf=xarm_res_pnt_pa_20170818.arf
rmf=xarm_res_h5ev_20170818.rmf
back=none
vignette=$vig_dir/SXT_VIG_140618.txt
psf=$psf_dir/eef_from_sxs_psfimage_20140618.fits

outfile=output/xarm_pointsource_sxs.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
```

```
decpoint=16.1085
roll=0.00
exposure=10000.
insrcdeffile=pointsource.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
resample=yes
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ###################

punlearn heasim
heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    resample=$resample \
    mdbfile=$mdbfile
```

where the `pointsource.txt` file is located in the heasimscripts/ directory and reads as follows:

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun,src_spec
151.8606,16.1085,1.0E21,pow,1.4,4.6e-10,0.5-10.0,none,2,2
```

To execute the script type the command

```
%>  sh sim_c1_sxsonly.sh >& sim_c1_sxsonly.log
```

This is equivalent to run on command line the command

```
heasim mission=hitomi instrume=SXS rapoint=151.8606 decpoint=16.1085 roll=0.00
exposure=10000.0 insrcdeffile=pointsource.txt outfile=xarm_pointsource_sxs.fits
psffile=$HEASIM_SUPPORT/hitomi/sxs/psf/sxs_psfimage_20140618.fits vigfile=NONE
rmffile=xarm_res_h5ev_20170818.rmf arffile=xarm_res_pnt_pa_20170818.arf arfrmftol=1.0e0
intbackfile=none psbackfile=none difbackfile=none pszbackfile=none resample=yes
skipfov=no dtpileup=0.0 getinfile=no debug=no clobber=yes mode=ql
mdbfile=$LHEA_DATA/heasim.mdb seed=99923112
```

Appendix C Examples ASTRO-H

This appendix contains examples for a variety of simulations for the Astro-H instruments. Each section describes a specific simulation, with details on the source definition file, the script used to execute the simulation, as well as the log (in some cases) and plots for the outputs. The *heasim* parameters used are listed in the scripts.
The support files to simulate the Astro-H events for all the focusing optic detectors are included in the heasimfiles/astro-h directory. Table 9 lists the filenames and the description of the files.

Table 9 Astro-H Supporting files for Simulation

Filename	**Description and Provenence**
HXI	
response/ ah_hxi_response_1dssd_20150729.rmf ah_hxi_response_20150729.rmf ah_hxt_pnt_r4_20150724.arf ah_hxt_pnt_r4intall_20150724.arf	Response for the top layer of HXI (1dssd) and the all layer ARF file derived for an extraction region of 4 arcmin ARF rescaled from 4 arcmin to full extent of EEF (factor 1/0.845)
background/ ah_hxi_1dssd_nxb_r4arcmin_20150727.pha ah_hxi_nxb_r4arcmin_20150727.pha ah_hxi_1dssd_nxb_r4intall_20150727.pha ah_hxi_nxb_r4intall_20150727.pha	Background file for the the top layder (1dssd) and all layers For an extraction radious of 4 arcmin Background files as above reescaled from 4 arcmin to full FOV (factor 1.5058)
instmap/ ah_hx1_instmap_20131001v004.fits ah_hx2_instmap_20131001v004.fits	These files are used in *heasim* and it is the field of view of the HXI1 and HXI2 detectors
vignette/ HXT_VIG_hm110105v2.txt	Based on estimates from Astro-H specifications
psf/ AstroH_HXI_EEF_090217.txt	Based on estimates from Astro-H specifications
SXI	
response/ ah_sxi_20120702.rmf sxt-i_140505_ts02um_int01.8r_intall.arf sxt- i_140505_ts02um_int01.8r_intall_140618psf.arf	The response for the SXI corresponsing to pre-launch estimate of the core of the line spread function ARF file derived for an extraction region of 1.8 arcmin (factor 1/0.64) ARFs file rescaled from 1.8 arcmin to include the full extent of the PSF (factor 1/.89)
background/ ah_sxi_pch_nxb_full_20110530.pi	Non X-ray background to include the full field of view of the SXI detector (36 x 36 arcmin)
instmap/ ah_sxi_instmap_20131001v004.fits	This file is used in *heasim* and it is the field of view of the SXI detector
vignette/ SXT_VIG_140618.txt SXT_VIG_140618_type1.fits SXT_VIG_140618_type2.fits	These files are necessary for *heasim*. This vignetting function is the pre-flight Astro-H expressed by a Lorentian function. The FWHM as function of energy is Energy(keV) FWHM(arcmin) 1.5 15.73

	4.51 15.21 8.04 11.76 9.44 9.61 11.07 8.29 12.94 7.42 For the energy < 10 keV, this is good out to 32 arcmin off-axis angle with about 5% accuracy. But for the energy > 10 keV, the data deviates from the Lorentzian at off-axis > 8 arcmin. The files contain the same information but given in different format * SXT_VIG_140618.txt plain ascii * SXT_VIG_140618_type1.fits one FITS extension with several columns one for a specific energy * SXT_VIG_140618_type2.fits several FITS extensions one for each energy
psf/ sxi_psfimage_20140618.fits eef_from_sxi_psfimage_20140618.fits	These files are used for *heasim* * sxi_psfimage_20140618.fits are images of the Astro-H PSF derived for on-axis position at 4.5 keV energy. The extend is 6 arcmin * eef_from_sxs_psfimage_20140618.fits are the Encircle Energy Function derived form sxs_psfimage_20140618.fits
SXS	
response/ ah_sxs_5ev_20130806.rmf ah_sxs_7ev_20130806.rmf ah_sxs_8ev_20130806.rmf ah_sxs_6ev_20130806.rmf ah_sxs_10ev_20150121.rmf ah_sxs_25ev_20130806.rmf	The responses are for different resolution and grades and include the quantum efficiency of the detector *5eV and 7eV are the required and goal resolution for H grade *6eV and 8eV are the required and goal resolution for M grade *10eV and 25eV are the required and goal resolution for L grade
sxt-s_140505_ts02um_intallpxl.arf sxt-s_140505_ts02um_Be_intallpxl.arf sxt-s_140505_ts02um_CBF_intallpxl.arf sxt-s_140505_ts02um_ND_intallpxl.arf	These ARFs for different filters for the SXS full array. Suitable to be use in XSPEC (factor 1/0.644) * Intallpxl Open filter * Be_intallpxl 26 um Be Filter * CBF_intallpxl Contamination Blocking filter * ND_intallpxl Neutral density filter
sxt-s_140505_ts02um_intall_140618psf.arf sxt-s_140505_ts02um_Be_intall_140618psf.arf sxt-s_140505_ts02um_CBF_intall_140618psf.arf sxt-s_140505_ts02um_ND_intall_140618psf.arf	These ARFs for different filters are the full PSF and suitable for *heasim*. These were obtained by rescaling the file for the Full SXS array using the PSF 20140618 (factor 1/0.89).
background/ sxs_nxb_4ev_20110211_1Gs.pha sxs_nxb_5ev_20110211_1Gs.pha sxs_nxb_7ev_20110211_1Gs.pha	Non X-ary background spectra for different energy resolution for H grades
instmap/ ah_sxs_instmap_20131001v004.fits	This file is used in *heasim* and it is the field of view of the SXS detector
vignette/	Same as the SXI description

SXT_VIG_140618.txt SXT_VIG_140618_type1.fits SXT_VIG_140618_type2.fits	
psf/ sxs_psfimage_20140618.fits eef_from_sxs_psfimage_20140618.fits	These files are used for *heasim* * sxs_psfimage_20140618.fits are images of the Astro-H PSF derived for on-axis position at energy 1.5 , 4.5, and 8 keV and at 4.5 arcmin offaxis position at energy 1.5keV. They extend to ~9 arcmin. * eef_from_sxs_psfimage_20140618.fits are the Encircle Energy Function derived form sxs_psfimage_20140618.fits
sxsbranch/ pixfrac.txt pixmap.fits pixmask.txt	These files are required for running *sxsbranch* * pixmap.fits :define pixels that are in electrical proximity * pixfrac.txt -- define the fractional distribution of counts in each pixel of the SXS array . This is calculated from a heasim simulation of a point source with a power law spectrum * pixmask.txt -- to exclude the outer 20 pixels from estimates and calculation of the branching ratios for either real or simulated event files.

All files in Table 9 that include the string “intall” have been rescaled from the original files. The original arf files were constructed to yield the counts from a point source of given flux in a region REG that does not fully encompass the psf. The “intall” files are scaled by 1.0/EEF(REG), where EEF(REG) is the eef fraction in that region (4.0 arcmin circle for HXI, 1.8 arcmin circle for SXI, the full array for SXS). *heasim* uses the scaled version to convert flux to counts for all photons -- including those outside the FOV -- using the EEF or PSF files. In addition, the HXI background spectra are scaled up to the full FOV from spectra created to be applied to a 4 arcmin extraction region.

The examples below show how to simulate single, multiple and extended sources, as well as one that uses *skyback* and another that applies *sxsbranch* to the output. The first example describes a *heasim* simulation of a simple point source for all Astro-H detectors, and may be of general interest for new users. The SXS output from this simulation is used as input to *sxsbranch*. The heasimscripts.tar.gz tarfile includes all of the scripts and supporting files needed to replicate these examples. To use XSELECT in a shell where the HEASIM_SUPPORT environmental variable is set, one should issue the command

%> setenv XSELECT_MDB $HEASIM_SUPPORT/auxiliary/xselect.mdb.heasim (C-shell),

or

%> export XSELECT_MDB=$HEASIM_SUPPORT/auxiliary/xselect.mdb.heasim (Bash).

If the HEASIM_SUPPORT evironmental variable is not set, xselect.mdb.heasim ought to be copied to the working directory rom $HEASIM_SUPPORT/auxiliary, or the full directory path should be specified.

Subsequently, within XSELECT, one should input

%> set wmapname x y

prior to extracting a spectrum from an event file.

C.1 Single point source with a simple spectrum

This simulation models a single point source with an absorbed power-law spectrum, observed with Astro-H for 10 ks at the standard aimpoint (on-axis with respect to the center of the SXS detector array), and with 0 roll angle.

The source definition file referenced in the script, pointsource.txt, reads as follows:

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun,src_spec
151.8606,16.1085,1.0E21,pow,1.4,4.6e-10,0.5-10.0,none,2,2
```

The following script contains the shell commands to set up and run *heasim*, saving the terminal output to a logfile (shown in the next subsection) via the command

%> sh alldetectors.sh >& alldetectors.log

Note that the pointing direction is set equal to the source position; for "offset" pointing these may be set to distinct values.

```
#! bin/sh

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"                                       # mission
instrume="sxs"                                          # instrument
cal_dir="sxs"                                           # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response     # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf           # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette      # vignette directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data        # directory containing source
files
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background   # int-bkg directory

arf=$resp_dir/sxt-s_140505_ts02um_intall_140618psf.arf
rmf=$resp_dir/ah_sxs_10ev_20150121.rmf
back=$back_dir/sxs_nxb_7ev_20110211_1Gs.pha
vignette=$vig_dir/SXT_VIG_140618.txt
psf=$psf_dir/eef_from_sxs_psfimage_20140618.fits

outfile=output/astroH_pointsource_sxs.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
```

```
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=10000.
insrcdeffile=pointsource.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ###################

punlearn heasim
heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    mdbfile=$mdbfile

instrume="sxi"                                          # instrument
cal_dir="sxi"                                           # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response     # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf           # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette      # vignette directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data                          #
directory containing source files
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background   # int-bkg directory

arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
rmf=$resp_dir/ah_sxi_20120702.rmf
back=$back_dir/ah_sxi_pch_nxb_full_20110530.pi
vignette=$vig_dir/SXT_VIG_140618.txt
psf=$psf_dir/sxt-i_EEF_4p5keV_140617.txt

outfile=output/astroH_pointsource_sxi.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=10000.
flagsubex=no
subexposure=10000.
insrcdeffile=pointsource.txt
outfile=$outfile
psffile=$psf
```

```
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ##################

heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    mdbfile=$mdbfile

instrume="hxi1"                                          # instrument
cal_dir="hxi"                                            # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response      # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf            # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette       # vignette directory
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background    # int-bkg directory

arf=$resp_dir/ah_hxt_pnt_r4intall_20150724.arf
rmf=$resp_dir/ah_hxi_response_20150729.rmf
back=$back_dir/ah_hxi_nxb_r4intall_20150727.pha
psf=$psf_dir/AstroH_HXI_EEF_090217.txt
vignette=$vig_dir/HXT_VIG_hm110105v2.txt

outfile=output/astroH_pointsource_hxi1.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=10000.
flagsubex=no
subexposure=10000.
insrcdeffile=pointsource.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ##################
```

```
heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    mdbfile=$mdbfile

instrume="hxi2"                                              # instrument
cal_dir="hxi"                                                # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response          # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf                # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette           # vignette directory
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background        # int-bkg directory

arf=$resp_dir/ah_hxt_pnt_r4intall_20150724.arf
rmf=$resp_dir/ah_hxi_response_20150729.rmf
back=$back_dir/ah_hxi_nxb_r4intall_20150727.pha
psf=$psf_dir/AstroH_HXI_EEF_090217.txt
vignette=$vig_dir/HXT_VIG_hm110105v2.txt

outfile=output/astroH_pointsource_hxi2.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=10000.
flagsubex=no
subexposure=10000.
insrcdeffile=pointsource.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ##################

heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
```

```
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    mdbfile=$mdbfile
```

C.1.1 Output Log

Below, the first (i.e., SXS) section of the output log file "alldetectors.log" is reproduced. Note that the SXS block has, by default, the subexposure flag set and two subsimulations are represented.

```
  Running HEASim, v. 2015-7-13


  Input Calibration files
   intbackfile  = none
   psffile      =
/Users/mloewens/astro/test_headas/astrohsim/ahsim/heasim/response/astro-
h/sxs/psf/eef_from_sxs_psfimage_20140618.fits
   vigfile      = none
   arffile      =
/Users/mloewens/astro/test_headas/astrohsim/ahsim/heasim/response/astro-
h/sxs/response/sxt-s_140505_ts02um_intall_140618psf.arf
   rmffile      =
/Users/mloewens/astro/test_headas/astrohsim/ahsim/heasim/response/astro-
h/sxs/response/ah_sxs_10ev_20150121.rmf
   arfrmftol    = 1.000000

 Global simulation info
   Pointing Direction (RA, DEC): 151.860600, 16.108500
   Exposure Time (s): 10000.000000
   Mission:    astro-h
   Instrument: sxs
   dtpileup: 0.000000

 Debugging mode: Disengaged

 Using user input seed = 1

Reading mission database file
/Users/mloewens/astro/test_headas/astrohsim/ahsim/x86_64-apple-
darwin14.4.0/refdata/heasim.mdb ...
...done.

Reading instrument map file...
...done.

All calibration files located successfully.

Confirmed that supplied RMF file is a valid RMF file.
Legacy HEASP reading RMF file into rmf_struct.......done.
```

```
Confirmed that supplied ARF file is a valid ARF file.
Legacy HEASP reading ARF file into arf_struct.......done.

Checking ARF/RMF compatibility...
ARF/RMF compatibiilty check passed successfully.

Nonzero RMF Energy Sensitivity: 0.033500 - 15.000501 keV.

Reading input file...
Found 1 valid sources in file pointsource.txt
...done.


Checking if sources fall within astro-h sxs detector (set debug=yes for more
detail)...
Pointing:  RA = 151.860600   Dec = 16.108500

Initializing output FITS file...
...done.

...done.
Reading PSF file...
...done.

Initializing Xspec models:
 Solar Abundance Vector set to angr:  Anders E. & Grevesse N. Geochimica et
Cosmochimica Acta 53, 197 (1989)
 Cross Section Table set to bcmc:  Balucinska-Church and McCammon, 1998
Done initializing Xspec models.

Optimizing sub-exposures for estimated 1009283 events...
Will simulate exposures such that:
  2 sub-exposures of 5000s

Processing 1 sources (set "debug=yes" for more detail)...

===== Processing exposure 1 of 2 (0s - 5000s). =====

===== Processing exposure 2 of 2 (5000s - 10000s). =====

...done processing sources.


Removed 164579 total (source+background) events that exceeded the PI channel
array.

Final number of:
               source events =     240332
           background events =          0
         ------------------------------------
                total events =     240332

Deallocating bin data...
...done.
Deallocating source data...
...done.
```

```
Deallocating source data...
...done.
Deallocating RMF data...
...done.
Deallocating ARF data...
...done.
Deallocating psf data...
...done.

Heasim finished with no errors, output file:
output/astroH_pointsource_sxs.fits
```

C.1.2 Output Images and Spectra

The output images are shown in Figure 1 with the 6 and 4 arcmin radius circular regions used to extract, respectively, the SXI and HXI1 spectra shown in Figure 2. Spectra and images were extracted using XSELECT from the astroH_pointsource_sxs.fits, astroH_pointsource_sxi.fits, astroH_pointsource_hxi2.fits, and astroH_pointsource_hxi2.fits *heasim* output files, and displayed using ds9 and XSPEC. The XSPEC best-fit spectral models correspond to the input spectral model (with fixed parameters) multiplied by a constant factor. Using the arf files sxt-i_140505_ts02um_int01.8r_intall.arf (ah_hxt_pnt_r4_20150724.arf) for the SXI (HXI1) fit, the factors in the best-fit models are 0.94 and 1.0, respectively, where the former reflects the chip gaps in the SXI. For the SXS (as with the HXI1, above), if one fits using the arf corrected for the fraction of the psf outside the FOV, sxt-s_140505_ts02um_intallpxl.arf, rather than the arf used in the simulation (see Table 5) the corresponding factor is 0.99.

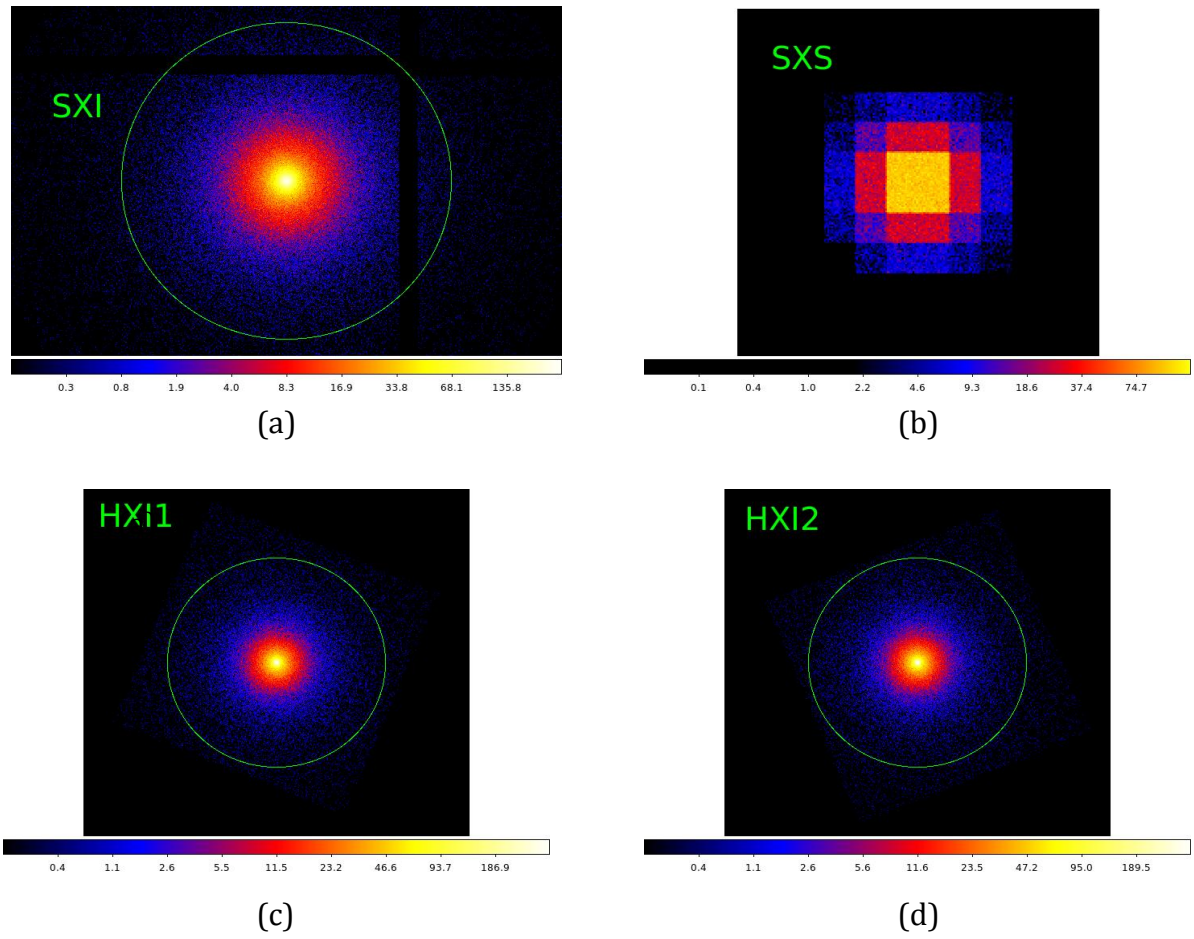


Figure 1. SXI (a), SXS (b), HXI1 (c), and (d) HXI2 images from simulation Example 1.The 6 and 4 arcminute radius circular spectral extraction regions for the SXI and HXI are shown as green circles.

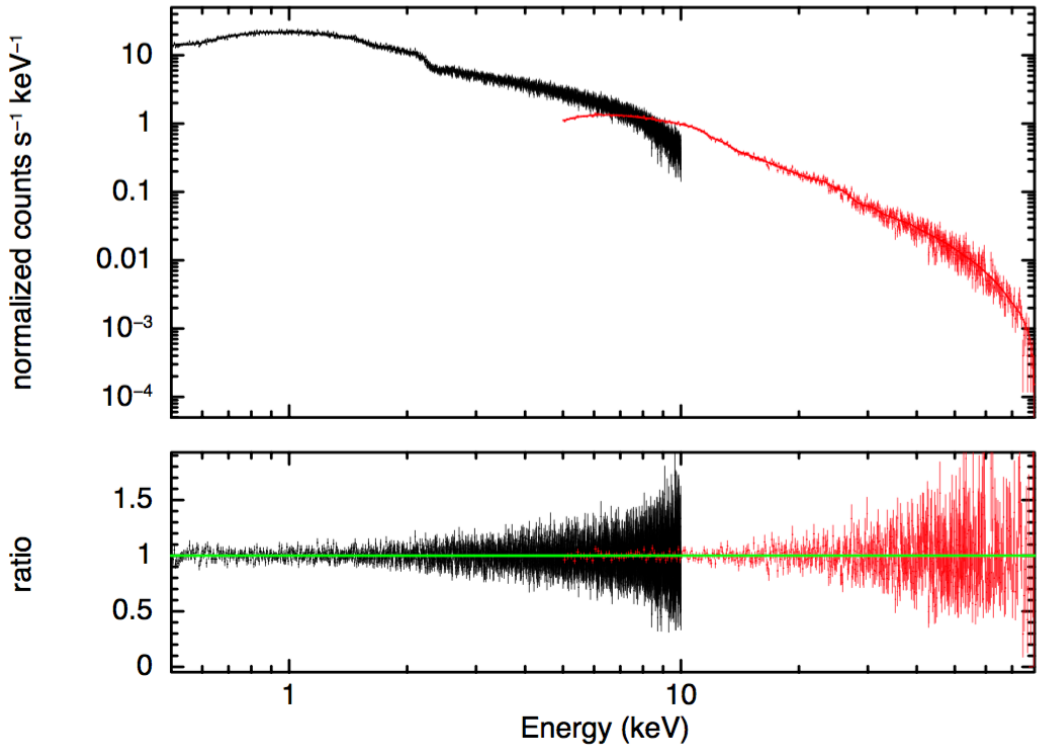


Figure 2. Extracted SXI and HXI1 spectra, and spectral fits, from simulation Example 1.

C.1.3 Sxsbranch

Here we take the output from the SXS simulation just conducted, and run the output through *sxsbranch* . Before start *sxsbranch* the TELESCOPE keyword of the simulated event file need to be set to HITOMI using the command:

```
%> fthedit output/astroH_pointsource_sxs.fits TELESCOPE add HITOMI
```

To run *sxsbranch* the commands are :

```
%> punlearn sxsbranch
%> pset sxsbranch debin=1.0
%> pset sxsbranch enrgthr = 10
%> pset sxsbranch ctphafrac1 = 0.00125
%> pset sxsbranch ctphafrac2 = 0.0005
%> pset sxsbranch ctelpixfile = $HEASIM_SUPPORT/astro-h/sxs/sxsbranch/pixmap.fits

%> sxsbranch output/astroH_pointsource_sxs.fits sim sxsbranch.out \
     pixfrac=$HEASIM_SUPPORT/astro-h/sxs/sxsbranch/pixfrac.txt pixmask=none
```

Only nearest-neighbor crosstalk for events with energies > 8 keV is induced using these parameters (see Section 5).

A copy of astroH_pointsource_sxs.fits, astroH_pointsource_sxs.fits.out, with additional PIXEL and ITYPE columns is created. Data from the BRANCHEST and BRANCHCALC extensions of the output file sxsbranch.out are compared, in Figure 3. The rates per pixel, color-coded by grade, are shown. Differences between the estimated branching ratios, and those calculated for the simulation are the result of (1) the absence of the calibration pixel in the simulation, and (2) the worst-case treatment of crosstalk in the estimate whereby every event induces crosstalk in electrical nearest and next-nearest neighbors.

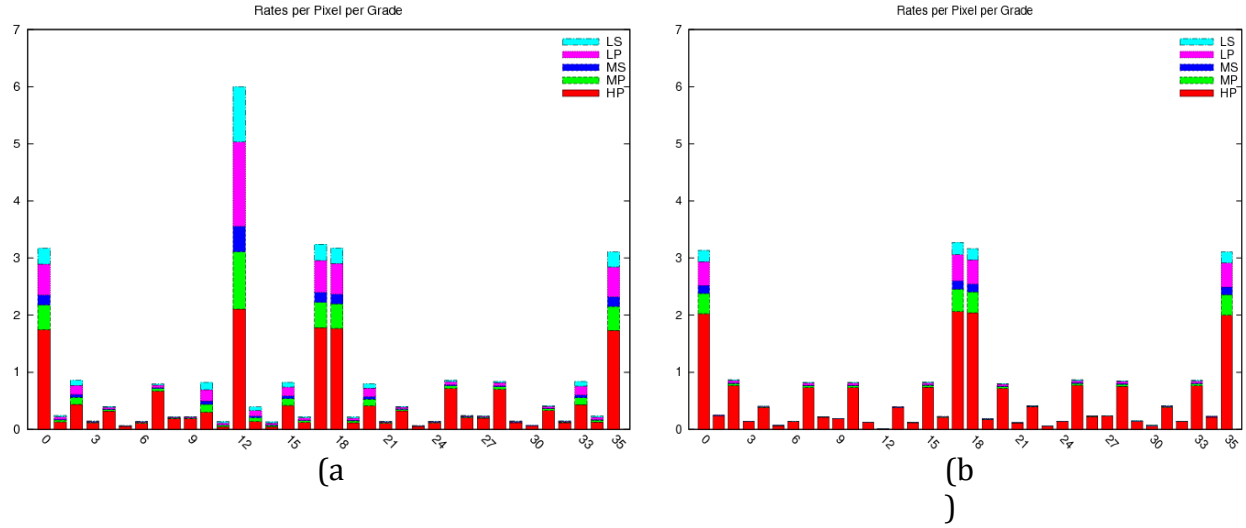


Figure 3. Results of applying *sxsbranch* to the SXS output from simulation Example 1. Rates in each grade, for each pixel, are shown based on estimates (assuming a rate of 6 cts s^{-1} in the cal-pixel) in (a), and as tabulated from the event file (b).

C.2 Very bright point source simulation split into subexposures

This simulation models a single point source with a power-law spectrum as in the previous example for the SXI, but with 100 times greater flux. The source definition file referenced in the script, brightsource.txt, reads as follows:

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun,src_spec
151.8606,16.1085,1.0E21,pow,1.4,4.6e-8,0.5-10.0,none,2,2
```

The following script contains the shell commands to set up and run *heasim*, saving the terminal output to a logfile (shown in the next subsection) via the command

%> sh ptsrc_bright_sxi_optsub.sh >& ptsrc_bright_sxi_optsub.log.

```
#! bin/sh

# if there's no output directory, then make it.
if [ ! -d output ]; then
```

```
    mkdir output
fi

mission="astro-h"                                          # mission
instrume="sxi"                                                # instrument
cal_dir="sxi"                                                 # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response           # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf                 # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette            # vignette directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data                                #
directory containing source files
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background         # int-bkg directory

arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
rmf=$resp_dir/ah_sxi_20120702.rmf
back=$back_dir/ah_sxi_pch_nxb_full_20110530.pi
vignette=$vig_dir/SXT_VIG_140618.txt
psf=$psf_dir/sxt-i_EEF_4p5keV_140617.txt

outfile=output/astroH_bright_sxi_optsub.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=10000.
flagsubex=yes
subexposure=1.0e9
insrcdeffile=brightsource.txt \
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ###################

heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    mdbfile=$mdbfile
```

C.2.1 Output Log

The output log file “ptsrc_bright_sxi_optsub.log” is similar in appearance to the SXI portion of alldetectors.log, except for the portion that appears as follows:

```
Optimizing sub-exposures for estimated 132945105 events...
Will simulate exposures such that:
  270 sub-exposures of 37s
  1 sub-exposure of 10s

Processing 1 sources (set "debug=yes" for more detail)...

===== Processing exposure 1 of 271 (0s - 37s). =====

===== Processing exposure 2 of 271 (37s - 74s). =====

===== Processing exposure 3 of 271 (74s - 111s). =====

...
===== Processing exposure 269 of 271 (9916s - 9953s). =====

===== Processing exposure 270 of 271 (9953s - 9990s). =====

===== Processing exposure 271 of 271 (9990s - 10000s). =====

...done processing sources.


Removed 9125802 total (source+background) events that exceeded the PI channel
array.

Final number of:
               source events =   52062943
           background events =          0
         ------------------------------------
                total events =   52062943

Deallocating bin data...
...done.
Deallocating source data...
...done.
Deallocating source data...
...done.
Deallocating RMF data...
...done.
Deallocating ARF data...
...done.
Deallocating psf data...
...done.

Heasim finished with no errors, output file:
output/astroH_bright_sxi_optsub.fits
```

This simulation has been split into 271 subexposures, each with ~200,000 cts.

C.3 Single point source with a bursting lightcurve

This simulation models a single point source with a power-law spectrum as in the previous example for the SXS, SXI, and HXI1 detectors. The emission is assumed to follow a lightcurve with a burst initiating 10 s after the start of the 1 ks exposure, (linear) risetime of 3 s, (exponential) decay time of 1 minute, and a ratio of peak-to-quiescent flux of 30.

The source definition file referenced in the script, plaw_burst.txt, reads as follows:

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun, \
# src_spec(tburst,trise,tdecay,burstratio)
151.8606,16.1085,0.0,pow,1.4,4.6e-10,2.0-10.0,none,2,2,burst(10.0,3.0,60.0,30.0)
```

Note that the flux refers to the average over the 1 ks observation.

The following script contains the shell commands to set up and run *heasim*, saving the terminal output to a logfile via the command

%> sh run_burst.sh >& run_burst.log.

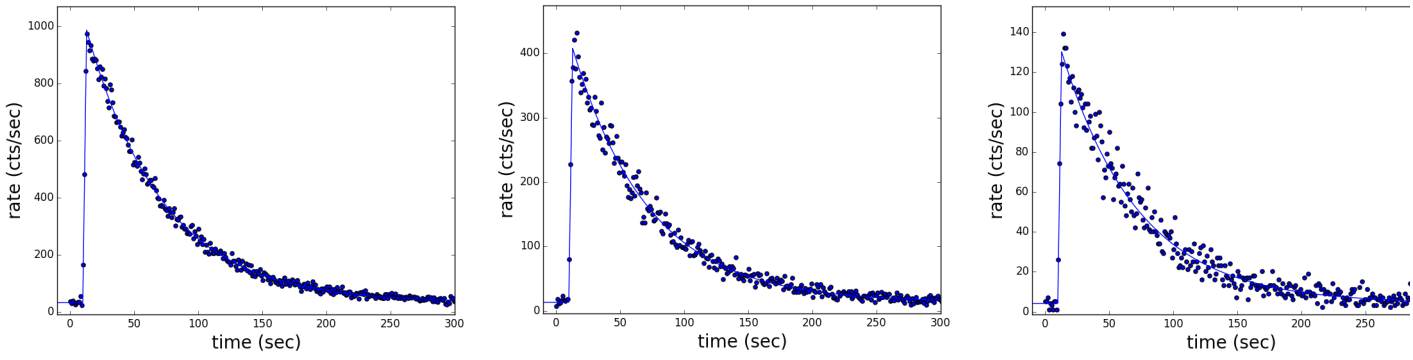
Here we reproduce only one (SXS) of the script assignment and execution blocks.

```
#! bin/sh

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"                                       # mission
instrume="sxs"                                          # instrument
cal_dir="sxs"                                           # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response     # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf           # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette      # vignette directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data        # directory containing source
files
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background   # int-bkg directory

arf=$resp_dir/sxt-s_140505_ts02um_intall_140618psf.arf
rmf=$resp_dir/ah_sxs_10ev_20150121.rmf
back=$back_dir/sxs_nxb_7ev_20110211_1Gs.pha
vignette=$vig_dir/SXT_VIG_140618.txt
psf=$psf_dir/eef_from_sxs_psfimage_20140618.fits

outfile=output/astroH_plaw_burst_sxs.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=1000.
flagsubex=no
subexposure=1000.
```

```
insrcdeffile=plaw_burst.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ##################

punlearn heasim
heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    mdbfile=$mdbfile
```

C.3.1 Output Lightcurves

Shown in Figure 4, from right to left, are the SXI, SXS, and HXI1 lightcurves in one-second bins (errorbars suppressed) compared to the input light curves (solid curves).



(a) (b) (c)

Figure 4. SXI (a), SXS (b), and HXI1 (c) lightcurves for output event files from simulation Example 3. Solid curves show the input light curve based on the source definition file "plaw_burst.txt."

C.4 Bright bursting source using flux division

This simulation is identical to the SXI block of the burst simulation described in the previous section, but with 100 times greater average flux.

The source definition file referenced in the perl script below, plaw_bburst.txt, reads as follows:

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun, \
# src_spec(tburst,trise,tdecay,burstratio)
151.8606,16.1085,0.0,pow,1.4,4.6e-8,2.0-10.0,none,2,2,burst(10.0,3.0,60.0,30.0)
```

The following command runs *heasim* 10 times, with an average flux for each run of one tenth that in the source definition file:

```
%> ./divide_flux.pl 10
```

where, by setting the root_name set equal to "burst," the output events files for each run "burstJ.evt.fits" (J=1-10) are output. These are merged into the summed, time-sorted, file "burst.evt.fits." A logfile, burst.log, is also created, as is the newly created source definition file with reduced flux, "subflux_plaw_burst.txt." The perl script, divide_flux.pl is reproduced below, and included in the ahsimscripts tarfile.

```
#! /usr/bin/perl

# If there's no output direcotry, then make it.
if (! -d "output"){
    mkdir "output";
}

# Get the number of flux subdivisions from the command line, i.e. calling sequence is:
#   ./divide_flux 5      - to have 5 subexposures equal in flux

my $N_flux = 1;
if ( defined $ARGV[0] ){
    $N_flux = $ARGV[0];
}


my $mission="astro-h";                                                  # mission
my $instrume="sxi";                                                     # instrume
my $cal_dir="sxi";                                                      # master
calibration data directory
my $resp_dir="$ENV{'HEASIM_SUPPORT'}/$mission/$cal_dir/response";    # response
directory
my $psf_dir="$ENV{'HEASIM_SUPPORT'}/$mission/$cal_dir/psf";          # psf directory
my $vig_dir="$ENV{'HEASIM_SUPPORT'}/$mission/$cal_dir/vignette";     # vignette
directory
my $back_dir="$ENV{'HEASIM_SUPPORT'}/$mission/$cal_dir/background"; # int-bkg
directory

my $arf="$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf";
my $rmf="$resp_dir/ah_sxi_20120702.rmf";
my $back="$back_dir/ah_sxi_pch_nxb_full_20110530.pi";
my $vignette="$vig_dir/SXT_VIG_140618.txt";
my $psf="$psf_dir/sxt-i_EEF_4p5keV_140617.txt";
my $mdbfile="$ENV{LHEA_DATA}/heasim.mdb";

my $ra=151.8606;
```

```
my $dec=16.1085;
my $pa=0.0;
my $expose=1000.;
my $root_name="burst";
my $logfile="$root_name.log";

my $input_src_file="plaw_bburst.txt";
my $sub_input_src_file="subflux_$input_src_file";

# If the logfile already exists, delete it.
if (-e "$logfile") {unlink "$logfile";}

# If the sub-divided flux filename already exists, delete it.
if (-e "$sub_input_src_file") {unlink "$sub_input_src_file";}

# Open $input_src_file for reading, $sub_input_src_file for writing.
open(my $FILE1, '<', $input_src_file);
open(my $FILE2, '>', $sub_input_src_file);
print $FILE2 "# ALL ORIGINAL FLUXES HAVE BEEN DIVIDED BY $N_flux.\n\n";

# Copy input source file to new source file, but divide fluxes by N_flux
while(my $line = <$FILE1>){
    chomp $line;
    $line =~ s/^\s+//;                    # Remove white space at beginning
    my $firstchar = substr($line, 0, 1);   # Get the first character in the line

    if (length $line > 0){                # If not a blank line
     if ($firstchar != "#") {           # If not a comment

         my @fields = split ",", $line; # Split the line into comma-delimited fields
         @fields[5] /= $N_flux;         # Flux is field 5; divide by N_flux

         # Append all fields into a new line
         my $new_line = "";
         for my $field (@fields) {$new_line .= "$field,";}

         # Remove the comma from the end of the new line
         $new_line = substr($new_line, 0, -1);

         # Print both the original line commented out, and the new line, to file
         print $FILE2 "# $line\n";
         print $FILE2 "  $new_line\n\n";

     } else { # Otherwise this line is a comment, just copy to new file as is.
         print $FILE2 "$line\n";
     }
    }
}

# Close the files
close $FILE1;
close $FILE2;

# Set the constant parameters
my @pset_commands = "";
push @pset_commands,"punlearn heasim";
push @pset_commands,"pset heasim mission=$mission";
push @pset_commands,"pset heasim instrume=$instrume";
push @pset_commands,"pset heasim rapoint=$ra";
push @pset_commands,"pset heasim decpoint=$dec";
push @pset_commands,"pset heasim roll=$pa";
push @pset_commands,"pset heasim exposure=$expose";
push @pset_commands,"pset heasim flagsubex=no";
```

```
push @pset_commands,"pset heasim subexposure=$expose";
push @pset_commands,"pset heasim psffile=$psf";
push @pset_commands,"pset heasim vigfile=none";
push @pset_commands,"pset heasim rmffile=$rmf";
push @pset_commands,"pset heasim arffile=$arf";
push @pset_commands,"pset heasim intbackfile=none";
push @pset_commands,"pset heasim debug=no";
push @pset_commands,"pset heasim clobber=yes";
push @pset_commands,"pset heasim mdbfile=$mdbfile";
push @pset_commands,"pset heasim insrcdeffile=$sub_input_src_file";

# Execute the psets
for my $command (@pset_commands) {system($command)};

# Write paramters to logfile
system("plist heasim 2>&1 | tee -a $logfile");


# Initialize a string of commands to merge the fits files later
my $merge_line = "";


# Loop over the flux subdivisions, calling heasim
for (my $NN=1; $NN <= $N_flux; $NN++){

    # Write a header to screen and to log, telling which block we're doing
    open(my $FILE3, '>>', $logfile);
    print "\n\n\n########## BEGINNING SUB-FLUX SIMULATION $NN of $N_flux ##########";
    print $FILE3 "\n\n\n########## BEGINNING SUB-FLUX SIMULATION $NN of $N_flux
##########";
    close $FILE3;

    # Execute the psets that change during each loop
    system("pset heasim outfile=output/$root_name$NN.evt");
    system("pset heasim seed=$NN");

    # Call heasim, pipe output to screen and to log
    system("heasim mode=hl 2>&1 | tee -a $logfile");

    # Append the output file name into the merge string
    $merge_line .= "output/$root_name$NN.evt.fits,"

}

# Remove the comma from the end of the merge line
$merge_line = substr($merge_line, 0, -1);

# If the final output files already exist, delete them
if (-e "output/$root_name.evt.fits")  {unlink "output/$root_name.evt.fits";}
if (-e "output/$root_name.sort.evt.fits")  {unlink "output/$root_name.sort.evt.fits";}

# Merge all the output fits files into one
system("ftmerge $merge_line output/$root_name.evt.fits");

# Sort the fits file by time
system("ftsort output/$root_name.evt.fits[EVENTS] output/$root_name.sort.evt.fits time
method=heap memory=yes copyall=yes");

# Rename the sorted fits file to main fits file
system("mv output/$root_name.sort.evt.fits output/$root_name.evt.fits");
```

C.5 Including Astrophysical Background

This simulation models a single point source with a power-law spectrum as in the previous examples. In this example we illustrate the application of SKYBACK to simulate the astrophysical background. In order to emphasize this component's contribution to the emission, we set the point source flux to a very low value, ignore the instrumental background, and set the *heasim exposure* parameter to 500 ks.

C.5.1 SKYBACK

Because of the distinct energy sensitivities of the SXI/SXS and HXI telescope-plus-detector systems, it is recommended to run SKYBACK separately over the two bandpasses. The parameters in the script below roughly produce average values of the 0.5-2.0 astrophysical background in the former, and of the 2-10 keV background in both the former and the latter.

The following script contains the shell commands to set up and run SKYBACK, saving the terminal output to a logfile (shown in the next subsection) via the command

%> sh skyback_sxi_hxi.sh >& skyback_sxi_hxi.log.

```
#! /bin/sh

# THIS SCRIPT RUNS THE SKY BACKGROUND TOOL.

############# ASSIGNMENT BLOCK ##############
# Create a definition block here, so we can preserve the useful comments for each
parameter

outfileroot="cxb_sxi" # Output file name base
exposure=10000     # exposure time in sec
ra=151.8606        # central RA in decimal degrees
dec=16.1085        # central Dec in decimal degrees
radius=50.0        # radius of FOV in arcmin
emin=0.1           # energy grid minimum in keV
emax=16.0          # energy grid maximum in keV
de=0.005           # energy grid spacing in keV
flaglogns=yes      # include emission from logN-logS ?
flaggal=yes        # include soft Xray Galactic and LHB emission ?
flagswcx=no        # include SWCX emission ?
slopebright1=1.7   # logN-logS slope 1, bright end
slopefaint1=0.9    # logN-logS slope 1, faint end
fluxbreak=2.5e-14  # logN-logS flux at power-law break
norm1=8.0e3        # logN-logS normalization in sources/sq.degree for slope 1
fluxsens=1.0e-14   # logN-logS flux sensitivity limit
fluxmin=1.0e-16    # lower flux limit of logN
fluxmax=5.0e-13    # upper flux limit of logNS in erg/cm^2/sec, both components
bandpasslo=0.5 # lower limit in keV for bandpass over which logN-logS is defined
bandpasshi=2.0 # upper limit in keV for bandpass over which logN-logS is defined
spectype1=1    # spectral type for slope-1 source: 0=single_spectrum, 1=multi, 2=torus
fabs0=0.22     # fraction of slope-1 sources, NH < 1e21 cm^-2
fabs1=0.22     # fraction of slope-1 sources, NH=1e21 - 1e22 cm^-2
fabs2=0.22     # fraction of slope-1 sources, NH=1e22 - 1e23 cm^-2
fabs3=0.22     # fraction of slope-1 sources, NH=1e23 - 1e24 cm^-2
fabs4=0.06     # fraction of slope-1 sources, NH=1e24 - 1e25 cm^-2
fabs5=0.06     # fraction of slope-1 sources, NH > 1e25 cm^-2
fpar0=0.2      # fraction index=1.5-1.7 if spectype1=1, opening angle < 30 if
spectype1=2
```

```
fpar1=0.2      # fraction index=1.7-1.9 if spectype1=1, opening angle 30-45 if
spectype1=2
fpar2=0.2      # fraction index=1.9-2.1 if spectype1=1, opening angle 45-60 if
spectype1=2
fpar3=0.2      # fraction index=2.1-2.3 if spectype1=1, opening angle 60-75 if
spectype1=2
fpar4=0.2      # fraction index=2.3-2.5 if spectype1=1, opening angle 75-90 if
spectype1=2
seed=1234567890

######### EXECUTION BLOCK ###################

punlearn skyback

skyback \
    outfileroot=$outfileroot \
    ra=$ra \
    dec=$dec \
    radius=$radius \
    emin=$emin \
    emax=$emax \
    de=$de \
    flaglogns=$flaglogns \
    flaggal=$flaggal \
    flagswcx=$flagswcx \
    slopebright1=$slopebright1 \
    slopefaint1=$slopefaint1 \
    fluxbreak=$fluxbreak \
    norm1=$norm1 \
    fluxsens=$fluxsens \
    fluxmin=$fluxmin \
    fluxmax=$fluxmax \
    bandpasslo=$bandpasslo \
    bandpasshi=$bandpasshi \
    spectype1=$spectype1 \
    fabs0=$fabs0 \
    fabs1=$fabs1 \
    fabs2=$fabs2 \
    fabs3=$fabs3 \
    fabs4=$fabs4 \
    fabs5=$fabs5 \
    fpar0=$fpar0 \
    fpar1=$fpar1 \
    fpar2=$fpar2 \
    fpar3=$fpar3 \
    fpar4=$fpar4 \
    seed=$seed

############## ASSIGNMENT BLOCK ##############
# Create a definition block here, so we can preserve the useful comments for each
parameter

outfileroot="cxb_hxi" # Output file name base
exposure=10000     # exposure time in sec
ra=151.8606        # central RA in decimal degrees
dec=16.1085        # central Dec in decimal degrees
radius=20.0        # radius of FOV in arcmin
emin=0.1           # energy grid minimum in keV
emax=120.0         # energy grid maximum in keV
de=0.025           # energy grid spacing in keV
flaglogns=yes      # include emission from logN-logS ?
flaggal=yes        # include soft Xray Galactic and LHB emission ?
flagswcx=no        # include SWCX emission ?
```

```
slopebright1=1.7   # logN-logS slope 1, bright end
slopefaint1=0.9    # logN-logS slope 1, faint end
fluxbreak=3.5e-14  # logN-logS flux at power-law break
norm1=1.9e4        # logN-logS normalization in sources/sq.degree for slope 1
fluxsens=1.0e-14   # logN-logS flux sensitivity limit
fluxmin=1.0e-16    # lower flux limit of logN
fluxmax=7.0e-13    # upper flux limit of logNS in erg/cm^2/sec, both components
bandpasslo=2.0     # lower limit in keV for bandpass over which logN-logS is defined
bandpasshi=10.0    # upper limit in keV for bandpass over which logN-logS is defined
spectype1=2  # spectral type for slope-1 source: 0=single_spectrum, 1=multi, 2=torus
fabs0=0.2    # fraction of slope-1 sources, NH < 1e21 cm^-2
fabs1=0.2    # fraction of slope-1 sources, NH=1e21 - 1e22 cm^-2
fabs2=0.2    # fraction of slope-1 sources, NH=1e22 - 1e23 cm^-2
fabs3=0.2    # fraction of slope-1 sources, NH=1e23 - 1e24 cm^-2
fabs4=0.1    # fraction of slope-1 sources, NH=1e24 - 1e25 cm^-2
fabs5=0.1    # fraction of slope-1 sources, NH > 1e25 cm^-2
fpar0=0.2    # fraction index=1.5-1.7 if spectype1=1, opening angle < 30 if
spectype1=2
fpar1=0.2    # fraction index=1.7-1.9 if spectype1=1, opening angle 30-45 if
spectype1=2
fpar2=0.2    # fraction index=1.9-2.1 if spectype1=1, opening angle 45-60 if
spectype1=2
fpar3=0.2    # fraction index=2.1-2.3 if spectype1=1, opening angle 60-75 if
spectype1=2
fpar4=0.2    # fraction index=2.3-2.5 if spectype1=1, opening angle 75-90 if
spectype1=2
seed=1234567890

######### EXECUTION BLOCK ###################

punlearn skyback

skyback \
    outfileroot=$outfileroot \
    ra=$ra \
    dec=$dec \
    radius=$radius \
    emin=$emin \
    emax=$emax \
    de=$de \
    flaglogns=$flaglogns \
    flaggal=$flaggal \
    flagswcx=$flagswcx \
    slopebright1=$slopebright1 \
    slopefaint1=$slopefaint1 \
    fluxbreak=$fluxbreak \
    norm1=$norm1 \
    fluxsens=$fluxsens \
    fluxmin=$fluxmin \
    fluxmax=$fluxmax \
    bandpasslo=$bandpasslo \
    bandpasshi=$bandpasshi \
    spectype1=$spectype1 \
    fabs0=$fabs0 \
    fabs1=$fabs1 \
    fabs2=$fabs2 \
    fabs3=$fabs3 \
    fabs4=$fabs4 \
    fabs5=$fabs5 \
    fpar0=$fpar0 \
    fpar1=$fpar1 \
    fpar2=$fpar2 \
    fpar3=$fpar3 \
```

```
    fpar4=$fpar4 \
    seed=$seed
```

C.5.1.1 Output Log and Files

The output log includes information such as the number of sources, and total resolved and unresolved fluxes from point sources.

Additional diagnostic output is provided when by setting the "debug" parameter to "YES."

```
  Running skyback, v. 2015-7-13


Using user input seed = 1234567890

Clobber engaged, removing files.

 Solar Abundance Vector set to angr:  Anders E. & Grevesse N. Geochimica et
Cosmochimica Acta 53, 197 (1989)
 Cross Section Table set to bcmc:  Balucinska-Church and McCammon, 1998

======== Computing point source contributions. ========
   ns_2 = 0
   flux_tot_2 =     0.000000e+00
   flux_res_2 =     0.000000e+00
   estflux_unr_2 =  0.000000e+00
   flux_unr_2 =     0.000000e+00
   ns_1 = 208
   flux_tot_1 =     1.504497e-11
   flux_res_1 =     5.352113e-12
   estflux_unr_1 =  9.217828e-12
   flux_unr_1 =     9.692853e-12
   samespec = 1, merging catalogs.
   Populating torus structs...
      Number of energies: 1000
   ...done populating torus structs.
   Total number of sources: 208
...done with point sources.

======== Computing galactic contributions. ========
   thalo_keV = 2.725000e-01
   fluxm = 9.560181e-12
   tlhb_keV = 1.085000e-01
   fluxc = 1.132901e-11
...done with galactic contributions.

Sky Background computation complete.
Primary output FITS file: difspec_cxb_sxi.fits
See also:
   difspec_cxb_sxi.dat (ASCII energy vs. spectra)
   pscat_cxb_sxi.txt (ASCII heasim point source input)
   difcat_cxb_sxi.txt (ASCII heasim diffuse source input)


  Running skyback, v. 2015-7-13
```

```
Using user input seed = 1234567890

Clobber engaged, removing files.

 Solar Abundance Vector set to angr:  Anders E. & Grevesse N. Geochimica et
Cosmochimica Acta 53, 197 (1989)
 Cross Section Table set to bcmc:  Balucinska-Church and McCammon, 1998

======== Computing point source contributions. ========
   ns_2 = 0
   flux_tot_2 =     0.000000e+00
   flux_res_2 =     0.000000e+00
   estflux_unr_2 =  0.000000e+00
   flux_unr_2 =     0.000000e+00
   ns_1 = 95
   flux_tot_1 =     6.112382e-12
   flux_res_1 =     2.587396e-12
   estflux_unr_1 =  3.499754e-12
   flux_unr_1 =     3.524986e-12
   samespec = 1, merging catalogs.
   Populating torus structs...
      Number of energies: 1000
   ...done populating torus structs.
   Total number of sources: 95
...done with point sources.

======== Computing galactic contributions. ========
   thalo_keV = 2.725000e-01
   fluxm = 1.529629e-12
   tlhb_keV = 1.085000e-01
   fluxc = 1.812642e-12
...done with galactic contributions.

Sky Background computation complete.
Primary output FITS file: difspec_cxb_hxi.fits
See also:
   difspec_cxb_hxi.dat (ASCII energy vs. spectra)
   pscat_cxb_hxi.txt (ASCII heasim point source input)
   difcat_cxb_hxi.txt (ASCII heasim diffuse source input)
```

The above script produces the following output files, to be used as *heasim* input as shown in the following subsections:

difcat_cxb_hxi.txt, pscat_cxb_hxi.txt, pszcat_cxb_hxi.txt, difcat_cxb_sxi.txt, pscat_cxb_sxi.txt, and pszcat_cxb_sxi.txt,

where the files labeled “sxi” are to be used for the SXS as well.

Lines in the “pscat” files have the structure of *heasim* source definitions files that appear as follows:

...

151.938267, 15.792395, 5.610000e+20, torus, 10907.000000, 6.607601e-14, 2.000000-10.000000, none, 1, 1
... (HXI)

or

152.255381, 16.403391, 5.610000e+20, pow, 1.537921, 5.825081e-14, 0.500000-2.000000, none, 1, 1
...
152.505569, 15.633707, 5.610000e+20, gilli_mild, 32210.000000, 2.315359e-14, 0.500000-2.000000, none, 1, 1
... (SXI/SXS),

those in the "pszcat" files augment these with a corresponding list of redshift and intrinsic column density, e.g.,

2.333014, 4.154450e+23.

The "difcat" files have the structure of *heasim* source definitions files for a flat spatial distribution extending to the SKYBACK "radius" input parameter, and with *heasim* user spectral files that specifically reference the SKYBACK ouput diffuse spectra, e.g.

151.860600, 16.108500, 0.0, user, 0, 0, 0.0-0.0, diffspec_cxb_sxi.dat, 1, 1, extmod(flat,0,50.0).

C.5.2 Heasim with Input From Skyback– Astro-H SXI, SXS, and HXI1

Below are the simulation steps that apply the SKYBACK output as just described as additional input to a *heasim* simulation.

In order to emphasize the background contribution a very weak point-source "ps_weak.txt", reproduced below, is simulated.

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun
```
151.8606,16.1085,0.0E00,pow,1.4,1.0e-15,2.0-10.0,none,2,2

The following script contains the shell commands to set up and run *heasim*, saving the terminal output to a logfile via the command

%> sh run_astroh_sxi_hxi_sxs_500k.sh >& run_astroh_sxi_hxi_sxs_500k.log.

Note that because we are using the same SKYBACK output for the SXI and SXS, in which the field-of-view radius parameter was set to 50 arcminutes to accomodate the former, a large number of messages are generated warning of sources that might off the (SXS) detector.

```
#! /bin/sh

# if there's no output directory, then make it.
```

```
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"
instrume="sxi"                                          # instrument
cal_dir="sxi"                                           # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response     # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf           # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette      # vignette directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data        # directory containing
source files
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background   # int-bkg directory

arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
rmf=$resp_dir/ah_sxi_20120702.rmf
back=$back_dir/ah_sxi_pch_nxb_full_20110530.pi
vignette=$vig_dir/SXT_VIG_140618.txt
psf=$psf_dir/sxt-i_EEF_4p5keV_140617.txt

outfile=output/astroH_cxb_sxi.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=500000.
flagsubex=no
subexposure=500000.
insrcdeffile=ps_weak.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
psbackfile=pscat_cxb_sxi.txt
difbackfile=difcat_cxb_sxi.txt
pszbackfile=pszcat_cxb_sxi.txt
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ##################

punlearn heasim
heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    subexposure=$subexposure \
    flagsubex=$flagsubex \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
```

```
    intbackfile=$intbackfile \
    psbackfile=$psbackfile \
    difbackfile=$difbackfile \
    pszbackfile=$pszbackfile \
    mdbfile=$mdbfile

instrume="hxi1"                                          # instrument
cal_dir="hxi"                                            # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response      # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf            # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette       # vignette directory
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background    # int-bkg directory

arf=$resp_dir/ah_hxt_pnt_r4intall_20150724.arf
rmf=$resp_dir/ah_hxi_response_20150729.rmf
back=$back_dir/ah_hxi_nxb_r4intall_20150727.pha
psf=$psf_dir/AstroH_HXI_EEF_090217.txt
vignette=$vig_dir/HXT_VIG_hm110105v2.txt

outfile=output/astroH_cxb_hxi1.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=500000.
flagsubex=no
subexposure=500000.
insrcdeffile=ps_weak.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
mdbfile=$LHEA_DATA/heasim.mdb
psbackfile=pscat_cxb_hxi.txt
difbackfile=difcat_cxb_hxi.txt
pszbackfile=pszcat_cxb_hxi.txt
mdbfile=$mdbfile

######### EXECUTION BLOCK ##################

heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
```

```
    psbackfile=$psbackfile \
    difbackfile=$difbackfile \
    pszbackfile=$pszbackfile \
    mdbfile=$mdbfile

instrume="hxi2"                                          # instrument
cal_dir="hxi"                                            # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response      # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf            # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette       # vignette directory
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background    # int-bkg directory

arf=$resp_dir/ah_hxt_pnt_r4intall_20150724.arf
rmf=$resp_dir/ah_hxi_response_20150729.rmf
back=$back_dir/ah_hxi_nxb_r4intall_20150727.pha
psf=$psf_dir/AstroH_HXI_EEF_090217.txt
vignette=$vig_dir/HXT_VIG_hm110105v2.txt

outfile=output/astroH_cxb_hxi2.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=500000.
flagsubex=no
subexposure=500000.
insrcdeffile=ps_weak.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
mdbfile=$LHEA_DATA/heasim.mdb
psbackfile=pscat_cxb_hxi.txt
difbackfile=difcat_cxb_hxi.txt
pszbackfile=pszcat_cxb_hxi.txt
mdbfile=$mdbfile

######### EXECUTION BLOCK ##################

heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    psbackfile=$psbackfile \
```

```
    difbackfile=$difbackfile \
    pszbackfile=$pszbackfile \
    mdbfile=$mdbfile

instrume="sxs"                                          # instrument
cal_dir="sxs"                                           # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response     # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf           # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette      # vignette directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data        # directory containing source
files
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background   # int-bkg directory

arf=$resp_dir/sxt-s_140505_ts02um_intall_140618psf.arf
rmf=$resp_dir/ah_sxs_10ev_20150121.rmf
back=$back_dir/sxs_nxb_7ev_20110211_1Gs.pha
vignette=$vig_dir/SXT_VIG_140618.txt
psf=$psf_dir/eef_from_sxs_psfimage_20140618.fits

outfile=output/astroH_cxb_sxs.fits

############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
rapoint=151.8606
decpoint=16.1085
roll=0.00
exposure=500000.
flagsubex=no
subexposure=500000.
insrcdeffile=ps_weak.txt
outfile=$outfile
psffile=$psf
vigfile=none
rmffile=$rmf
arffile=$arf
intbackfile=none
psbackfile=pscat_cxb_sxi.txt
difbackfile=difcat_cxb_sxi.txt
pszbackfile=pszcat_cxb_sxi.txt
mdbfile=$LHEA_DATA/heasim.mdb

######### EXECUTION BLOCK ##################

heasim \
    mission=$mission \
    instrume=$instrume \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    intbackfile=$intbackfile \
    psbackfile=$psbackfile \
```

```
difbackfile=$difbackfile \
pszbackfile=$pszbackfile \
mdbfile=$mdbfile
```

C.5.2.1 Output Images and Spectra From Heasim with Skyback Input

Shown in Figure 5 are the SXI, SXS, and HXI images (binned by factors of 8, 19, and 4 respectively) and spectra extracted from the entire field. The spectra were fit with the XSPEC model

constant*phabs*powerlaw + constant*raymond + constant*phabs*raymond

with an overall scaling between detectors, and the power-law absorption and index allowed to vary between the HXI and SXI/SXS detectors.

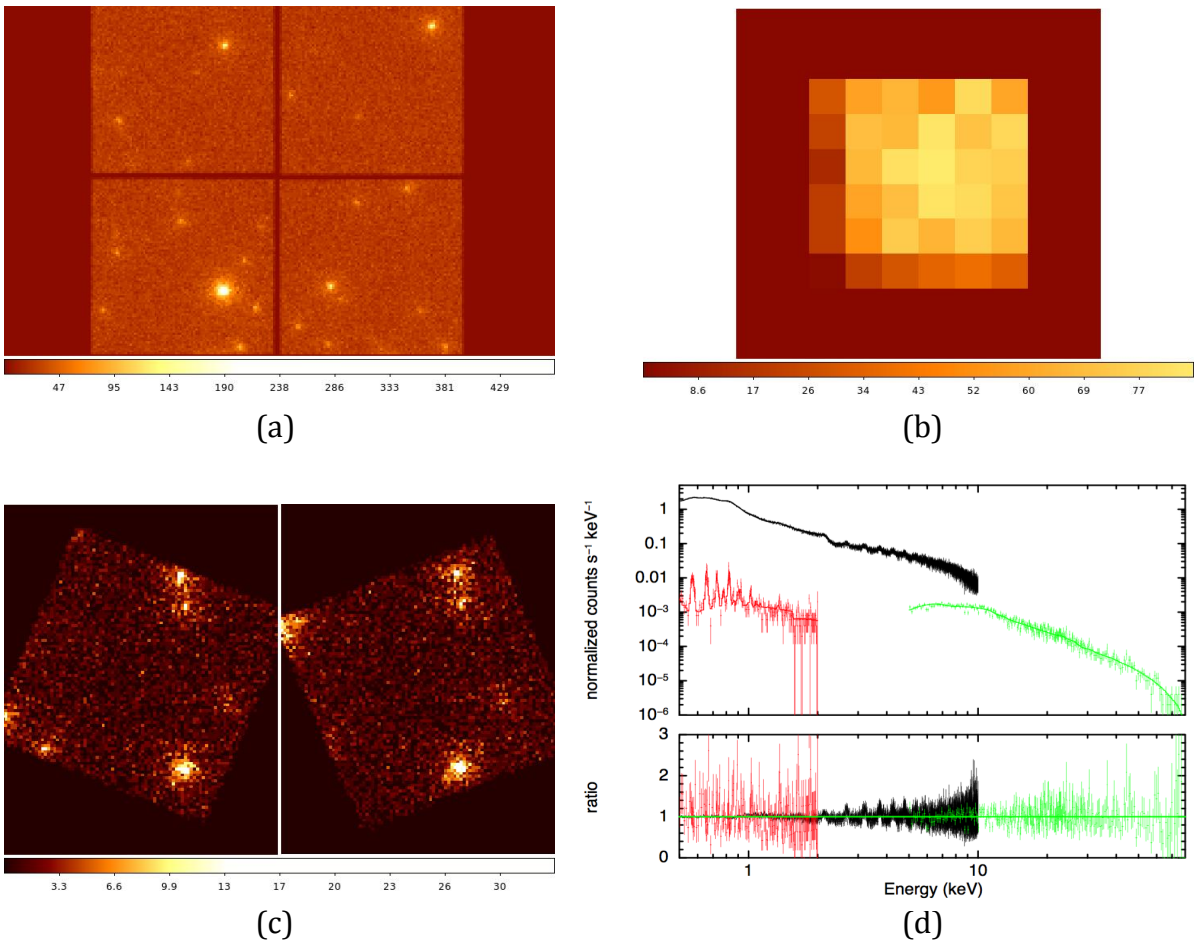


Figure 5. SXI (a), SXS (b), and HXI1 and HX2 (c) images for output event files from simulation Example 5, corresponding to pure astrophysical background as modeled with *skyback*. The SXI (black), SXS (red), and HXI (yellow) spectra are for the full fields, and fit as described in the text.

C.6 Multiple Point Sources

This example simulates three point sources observed with the Astro-H SXI: a blackbody with temperature kT = 0.5 keV; a power-law source with Γ = 1.5; and another power-law source with Γ = 2.0.

The source definition file referenced in the script, "point_multi_input.dat", reads as follows:

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun,src_spec
81.5,-69.5,1.0E+21,blac,0.5,1.0E-11,2.0-10.0,none,2,2;
81.7,-69.5,1.0E+21,pow,1.5,1.0E-10,2.0-10.0,none,2,2;
81.5,-69.7,1.0E+21,pow,2.0,5.0E-10,2.0-10.0,none,2,2;
```

The following script contains the shell commands to set up and run *heasim*, saving the terminal output to a logfile:

```
%> sh point_multi.sh
```

```
#!/bin/sh

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"                                          # mission
instrume="sxi"                                             # instrument
cal_dir="sxi"                                                    # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response    # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf          # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette     # vignette directory
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background  # background directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data         # directory containing source
files
fileroot=sim1e_sxi_multi

rmf=$resp_dir/ah_sxi_20120702.rmf
arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
outfile=output/${fileroot}.fits

punlearn heasim
heasim mission = $mission \
     instrume = $instrume \
     filter = none \
     instmode = none \
     rapoint = 81.5 \
     decpoint = -69.5 \
     roll = 0.00 \
     exposure = 10000. \
     flagsubex =  no \
     subexposure = 1.0e9 \
     insrcdeffile = point_multi_input.dat \
     outfile = $outfile \
     psffile = $psf_dir/sxt-i_EEF_4p5keV_140617.txt \
     vigfile = $vig_dir/SXT_VIG_140618.txt \
```

```
      rmffile = $rmf \
      arffile = $arf \
      arfrmftol = 1.0e0 \
      intbackfile = $back_dir/ah_sxi_pch_nxb_full_20110530.pi \
      psbackfile = none \
      difbackfile = none \
      pszbackfile = none \
      dtpileup = 0.0 \
      getinfile = no \
      debug = yes \
      clobber = yes \
      mode = ql \
      mdbfile = $LHEA_DATA/heasim.mdb \
      seed = 0 | tee output/${fileroot}.log
# if == 0, ignore and seed using system time
```

C.6.1 Output Images and Spectra

The SXI counts images are shown in Figure 6, along with the spectrum of each source (circled in green in the image). The background region (in magenta) has been subtracted from the spectra.

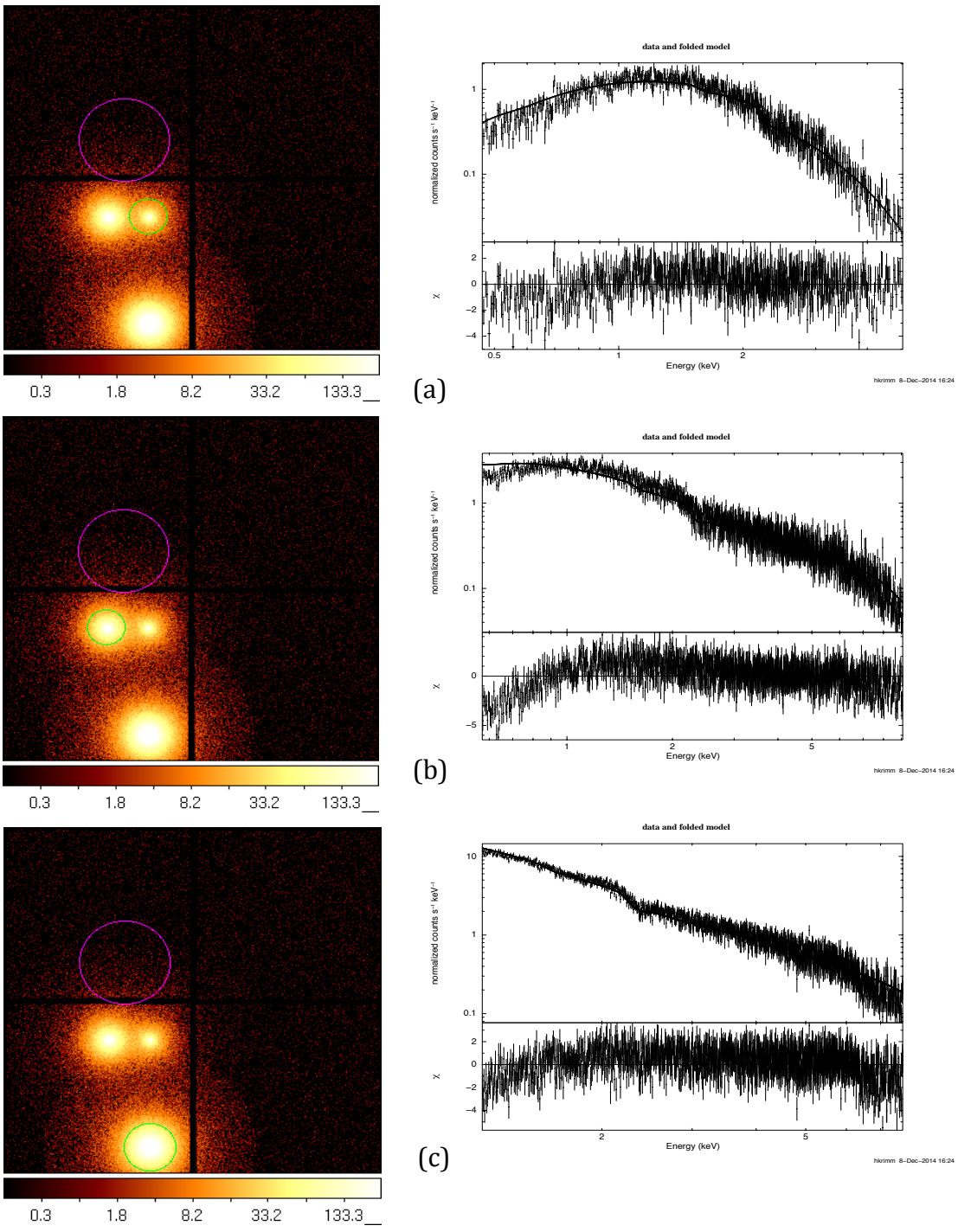


Figure 6. SXI images and spectra for output event files from simulation Example 6. Source and background spectra are extracted from the yellow and magenta circles, respectively.

C.7 Multiple Point Sources with Roll Angle

This example is identical to the previous example, simulating three point sources observed with the Astro-H SXI. However, now a roll angle of 30 degrees has been introduced. The spectra for the three sources are, as before: a blackbody with temperature kT=0.5 keV; a power-law source with $\Gamma = 1.5$; and another power-law source with $\Gamma = 2.0$.

The source definition file referenced in the script, "point_multi_input.dat", reads as follows:

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun,src_spec
81.5,-69.5,1.0E+21,blac,0.5,1.0E-11,2.0-10.0,none,2,2;
81.7,-69.5,1.0E+21,pow,1.5,1.0E-10,2.0-10.0,none,2,2;
81.5,-69.7,1.0E+21,pow,2.0,5.0E-10,2.0-10.0,none,2,2;
```

The following script contains the shell commands to set up and run *heasim*, saving the terminal output to a logfile:

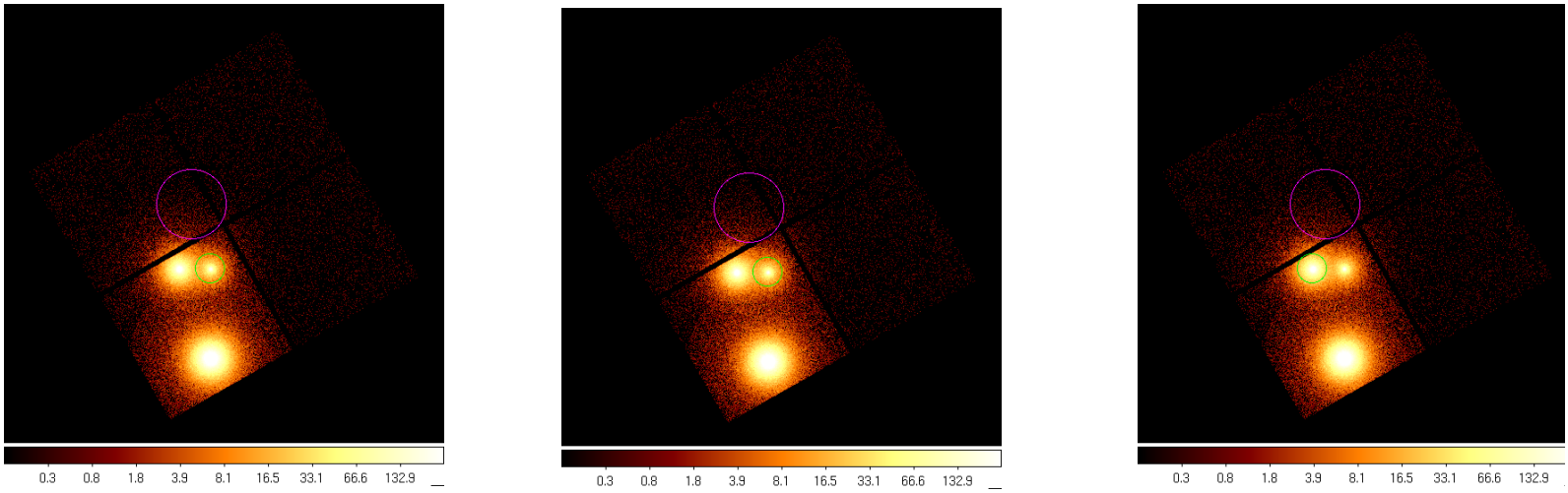
```
%> sh point_multi_roll.sh
```

```
#!/bin/sh

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"                                          # mission
instrume="sxi"                                             # instrume
cal_dir="sxi"                                              # master calibration data
directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response    # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf          # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette     # vignette directory
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background  # background directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data       # directory containing source
files
fileroot=sim1f_sxi_multi_roll

rmf=$resp_dir/ah_sxi_20120702.rmf
arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
outfile=output/${fileroot}.fits

punlearn heasim
heasim mission = $mission \
     instrume = $instrume \
     filter = none \
     instmode = none \
     rapoint = 81.5 \
     decpoint = -69.5 \
     roll = 30.00 \
     exposure = 10000. \
     flagsubex =  no \
     subexposure = 1.0e9 \
     insrcdeffile = point_multi_input.dat \
     outfile = $outfile \
     psffile = $psf_dir/sxt-i_EEF_4p5keV_140617.txt \
     vigfile = $vig_dir/SXT_VIG_140618.txt \
     rmffile = $rmf \
     arffile = $arf \
```

```
      arfrmftol = 1.0e0 \
      intbackfile = $back_dir/ah_sxi_pch_nxb_full_20110530.pi \
      psbackfile = none \
      difbackfile = none \
      pszbackfile = none \
      dtpileup = 0.0 \
      getinfile = no \
      debug = yes \
      clobber = yes \
      mode = ql \
      mdbfile = $LHEA_DATA/heasim.mdb \
      seed = -1 | tee output/${fileroot}.log
# if == 0, ignore and seed using system time
```

C.7.1 Output Images and Spectra

The SXI counts images are shown In Figure 7; the spectra are identical to those in Figure 6. The image is shown in sky coordinates, so the roll angle of 30 degrees is clearly seen.



(a) (b) (c)

Figure 7. SXI images for output event files from simulation Example 7.

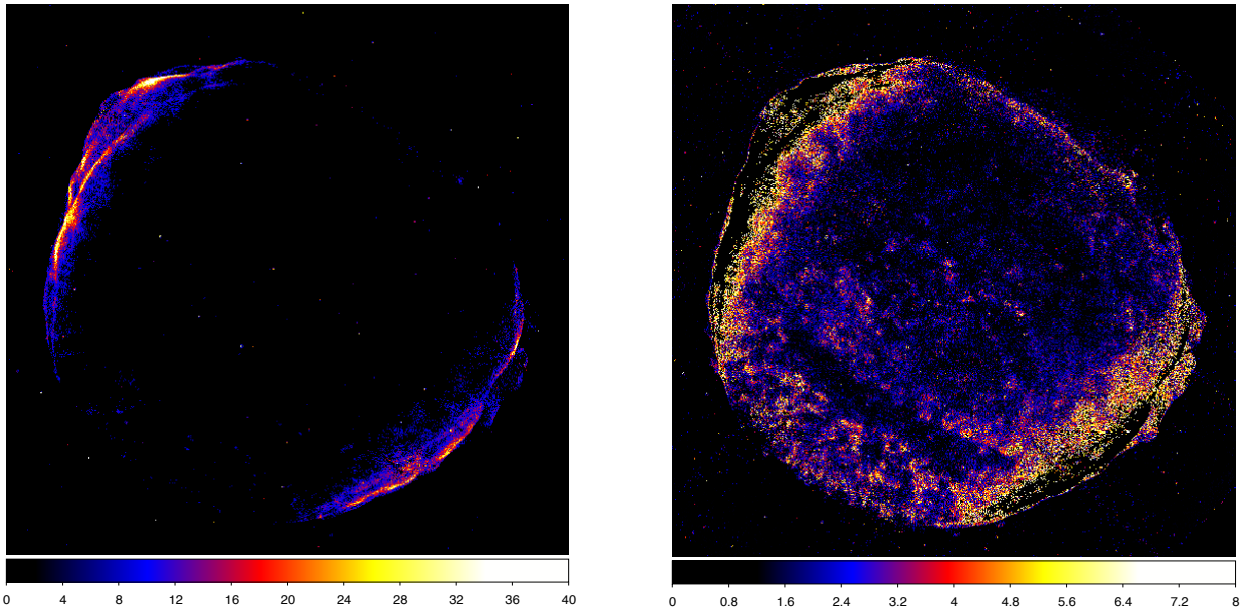
C.8 Extended Source – Supernova Remnant (SNR) with Spatially-Varying Spectra

This example uses multiple *Chandra* images each with distinct spectral models as input sources. The images are of the SN 1006 supernova remnant, with a shell of non-thermal emission surrounding a diffuse region of thermal emission. 100 ks simulations are performed for the Astro-H SXI, SXS, and HXI instruments.

The source definition file referenced in the script, “sim_sn1006_sxi.txt”, reads as follows:

0.0,0.0,1e21,pow,2.8,8e-10,0.5-30.0,none,2,2, \ image(CXO_image/sn1006_shell.fits,0,0,0,0)
0.0,0.0,1e21,rs,0.4,2e-10,0.5-10.0,none,2,2, \ image(CXO_image/sn1006_inner.fits,0,0,0,0)

FITS file images ahsimscripts/CXO_image/sn1006_[shell/inner].fits are shown in Figure 8. These images must have WCS information in the header, and (ra,dec) are ignored and need not be set in source definition file.



(a) (b)

Figure 8. Input Chandra images for simulation Example 8: the non-thermal region image sn1006_shell.fits (a), and the thermal region image sn1006_inner.fits (b).

The following script contains the shell commands to set up and run *heasim*, saving the terminal output to a logfile via the command

%> sh sim_sn1006_sxi.sh >& sim_sn1006_sxi.log.

The script for one example instrument (SXI) is shown. The optimized division into subexposures is enabled in this bright source example.

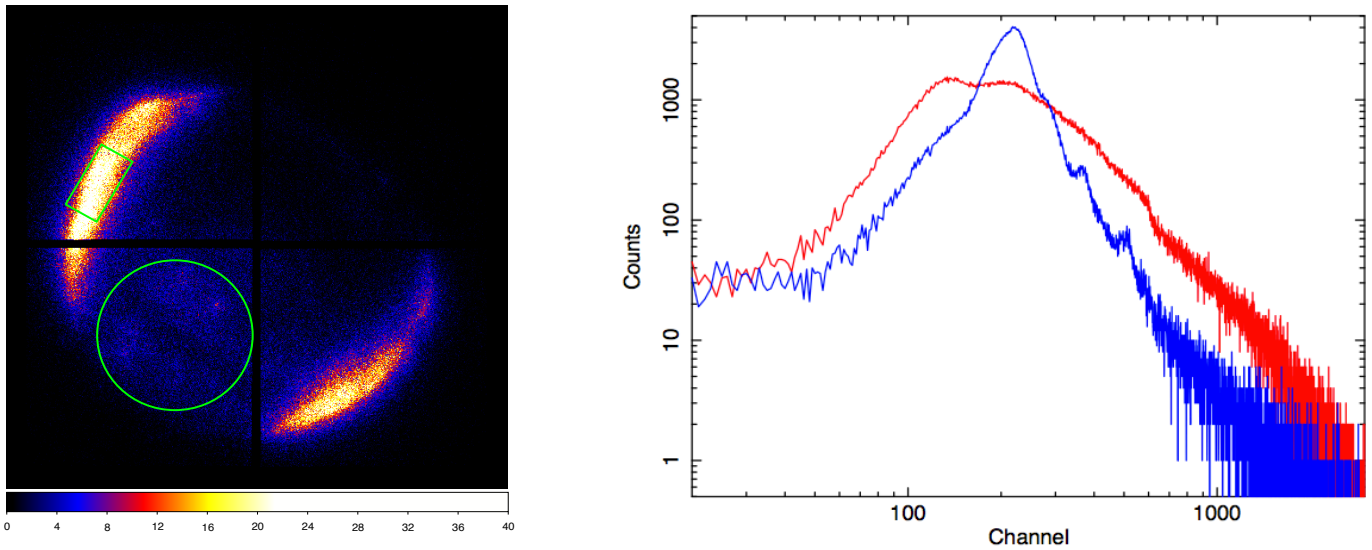
```
#! /bin/sh

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"                              # mission
instrume="sxi"                                 # instrument
cal_dir="sxi"                                  # master calibration data directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response    # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf          # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette     # vignette directory
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background  # background directory
```

```
#source_dir=$HEASIM_SUPPORT/testdata/source_data       # directory containing source
files

arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
rmf=$resp_dir/ah_sxi_20120702.rmf
psf=$psf_dir/sxt-i_EEF_4p5keV_140617_type1.fits
vig=$vig_dir/SXT_VIG_140618_type1.fits
back=$back_dir/ah_sxi_pch_nxb_full_20110530.pi

infile=sim_sn1006_sxi.txt
outfile=output/astroH_sxi_sn1006_test1.fits


############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
filter=none
instmode=none
rapoint=225.8
decpoint=-41.98
roll=0.00
flagsubex=yes
exposure=100000.
subexposure=1.0e9
insrcdeffile=$infile
outfile=$outfile
psffile=$psf
vigfile=$vig
rmffile=$rmf
arffile=$arf
arfrmftol=1.0e0
intbackfile=$back
psbackfile=none
difbackfile=none
pszbackfile=none
dtpileup=0.0
getinfile=no
debug=no
clobber=yes
mode=ql
mdbfile=$LHEA_DATA/heasim.mdb
seed=1234567890    # if == 0, ignore and seed using system time


######### EXECUTION BLOCK ##################

punlearn heasim
heasim \
    mission=$mission \
    instrume=$instrume \
    filter=$filter \
    instmode=$instmode \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
```

```
rmffile=$rmffile \
arffile=$arffile \
arfrmftol=$arfrmftol \
intbackfile=$intbackfile \
psbackfile=$psbackfile \
difbackfile=$difbackfile \
pszbackfile=$pszbackfile \
dtpileup=$dtpileup \
getinfile=$getinfile \
debug=$debug \
clobber=$clobber \
mode=$mode \
mdbfile=$mdbfile
```

C.8.1 Output Images and Spectra

The SXI image is shown Figure 9, along with the spectrum extracted from the indicated regions.



(a) (b)

Figure 9. SXI image (a) and spectra (b) for output event files from simulation Example 8. The red curve in the spectra is extracted from the northeast shell, the blue from the southeast circular region.

C.9 Extended Source – Pulsed Point Source Embedded in Extended Source with Distinct Spectrum

This example simulates a point source with a power-law spectrum and sinusoidal pulsation combined with a uniform surface brightness annular source with a stable, thermal spectrum. This is intended to approximate a SNR with a central pulsar. Simulations are performed for the Astro-H SXI.

The source definition file referenced in the script, "sim_SNRwPSR.txt", reads as follows:

180.0,0.0,5.0E21,pow,2.5,1e-10,0.5-10.0,none,2,2,pulse(1000,0.5)
180.0,0.0,5.0E21,rs,1.0,5e-10,0.5-10.0,none,2,2,extmod(flat,2,8)

The following script contains the shell commands to set up and run *heasim*, saving the terminal output to a logfile via the command

%> sh sim_SNRwPSR.sh >& sim_SNRwPSR.log.

```
#! /bin/sh

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"                        # mission
instrume="sxi"                           # instrument
cal_dir="sxi"                            # master calibration data directory
resp_dir=$HEASIM_SUPPORT/$mission/$cal_dir/response    # response directory
psf_dir=$HEASIM_SUPPORT/$mission/$cal_dir/psf          # psf directory
vig_dir=$HEASIM_SUPPORT/$mission/$cal_dir/vignette     # vignette directory
back_dir=$HEASIM_SUPPORT/$mission/$cal_dir/background  # background directory
#source_dir=$HEASIM_SUPPORT/testdata/source_data       # directory containing source
files

arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
rmf=$resp_dir/ah_sxi_20120702.rmf
psf=$psf_dir/sxt-i_EEF_4p5keV_140617_type1.fits
vig=$vig_dir/SXT_VIG_140618_type1.fits
back=$back_dir/ah_sxi_pch_nxb_full_20110530.pi

infile=sim_SNRwPSR.txt
outfile=output/astroH_sxi_psr.fits


############# ASSIGNMENT BLOCK ##############

mission=$mission
instrume=$instrume
filter=none
instmode=none
rapoint=180.00
decpoint=00.00
roll=0.00
exposure=40000.
flagsubex=no
subexposure=40000.
insrcdeffile=$infile
outfile=$outfile
psffile=$psf
vigfile=$vig
rmffile=$rmf
arffile=$arf
arfrmftol=1.0e0
intbackfile=$back
psbackfile=none
difbackfile=none
pszbackfile=none
dtpileup=0.0
```

```
getinfile=no
debug=no
clobber=yes
mode=ql
mdbfile=$LHEA_DATA/heasim.mdb
seed=1234567890    # if == 0, ignore and seed using system time


######### EXECUTION BLOCK ##################

heasim \
    mission=$mission \
    instrume=$instrume \
    filter=$filter \
    instmode=$instmode \
    rapoint=$rapoint \
    decpoint=$decpoint \
    roll=$roll \
    exposure=$exposure \
    flagsubex=$flagsubex \
    subexposure=$subexposure \
    insrcdeffile=$insrcdeffile \
    outfile=$outfile \
    psffile=$psffile \
    vigfile=$vigfile \
    rmffile=$rmffile \
    arffile=$arffile \
    arfrmftol=$arfrmftol \
    intbackfile=$intbackfile \
    psbackfile=$psbackfile \
    difbackfile=$difbackfile \
    pszbackfile=$pszbackfile \
    dtpileup=$dtpileup \
    getinfile=$getinfile \
    debug=$debug \
    clobber=$clobber \
    mode=$mode \
    mdbfile=$mdbfile
```

C.9.1 Output Images, Lighcurves, and Spectra

The SXI image is shown Figure 10, along with the spectra and lighcurves extracted from the “pulsar” and “ remnant” regions as indicated.

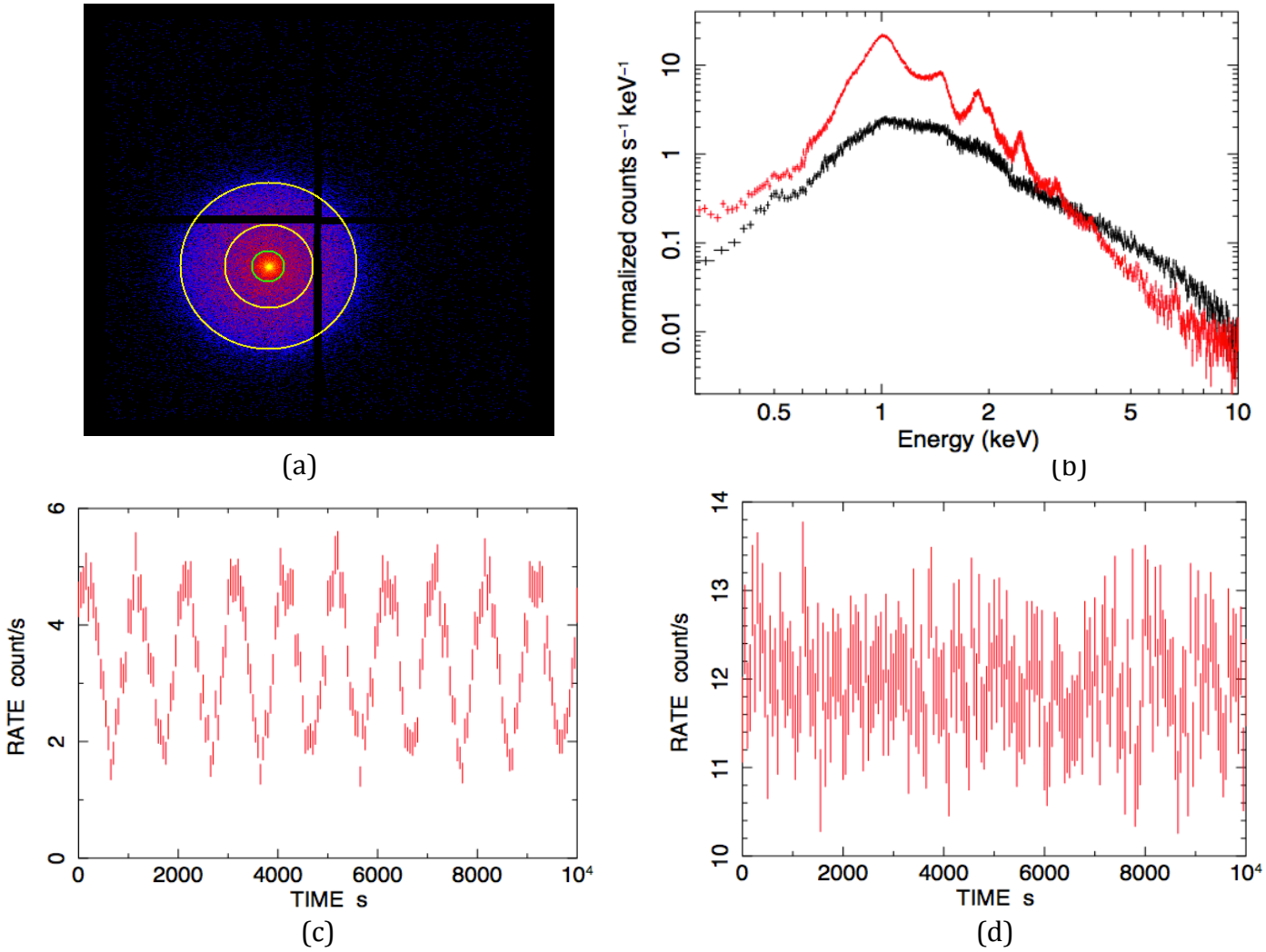


Figure 10. SXI image (a), spectrum (b), and lightcurves (c,d) for output event files from simulation Example 9. The black spectrum and lightcurve on the left are extracted from the 1.5 arcmin circular "pulsar" region (green circle), the red spectrum and lightcurve on the right are extracted from the 4.0–8.0 arcmin annular "SNR" region (yellow annulus).

C.10 Extended Source – Galaxy Cluster with Beta-Model Surface Brightness Profile and Temperature Gradient

This example simulates a 100 ks SXI observation of a cluster of galaxies with a beta-model surface brightness profile and typical temperature gradient with a cool core rising to a peak temperature and then falling off in the cluster outskirts. It is based loosely on results for Abell 1795 from XMM and Suzaku data (Snowden et al. 2008, Bautz et al. 2009).

The file "cluster_beta_tempgradient_sxi.dat" contains one row for each radial bin of the cluster. Each row has a different flux and temperature to account for the radial dependence.

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun,src_spec
# a 1'-core elliptical beta-model distribution w/ temperature profile
# based loosely on A1795 from Snowden et al. 2008 and Bautz et al. 2009
207.215,26.588,1.2e20,rs,3.8,1.0e-11,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,0.0,0.5)
207.215,26.588,1.2e20,rs,4.5,1.5e-11,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,0.5,1.0)
207.215,26.588,1.2e20,rs,5.2,2.2e-11,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,1.0,2.0)
207.215,26.588,1.2e20,rs,5.5,1.4e-11,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,2.0,3.0)
207.215,26.588,1.2e20,rs,5.5,1.0e-11,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,3.0,4.0)
207.215,26.588,1.2e20,rs,5.2,7.4e-12,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,4.0,5.0)
207.215,26.588,1.2e20,rs,5.0,1.1e-11,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,5.0,7.0)
207.215,26.588,1.2e20,rs,4.7,7.0e-12,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,7.0,9.0)
207.215,26.588,1.2e20,rs,4.0,5.0e-12,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,9.0,11.0)
207.215,26.588,1.2e20,rs,3.4,3.0e-12,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,11.0,13.0)
207.215,26.588,1.2e20,rs,2.6,1.8e-12,0.3-10.,none,2,2,extmod(beta,0.67,1.0,1.0,0.0,13.0,15.0)
```

The following script was used to run heasim. The script produces its own logfile, so it can simply be run from the command line via a command like

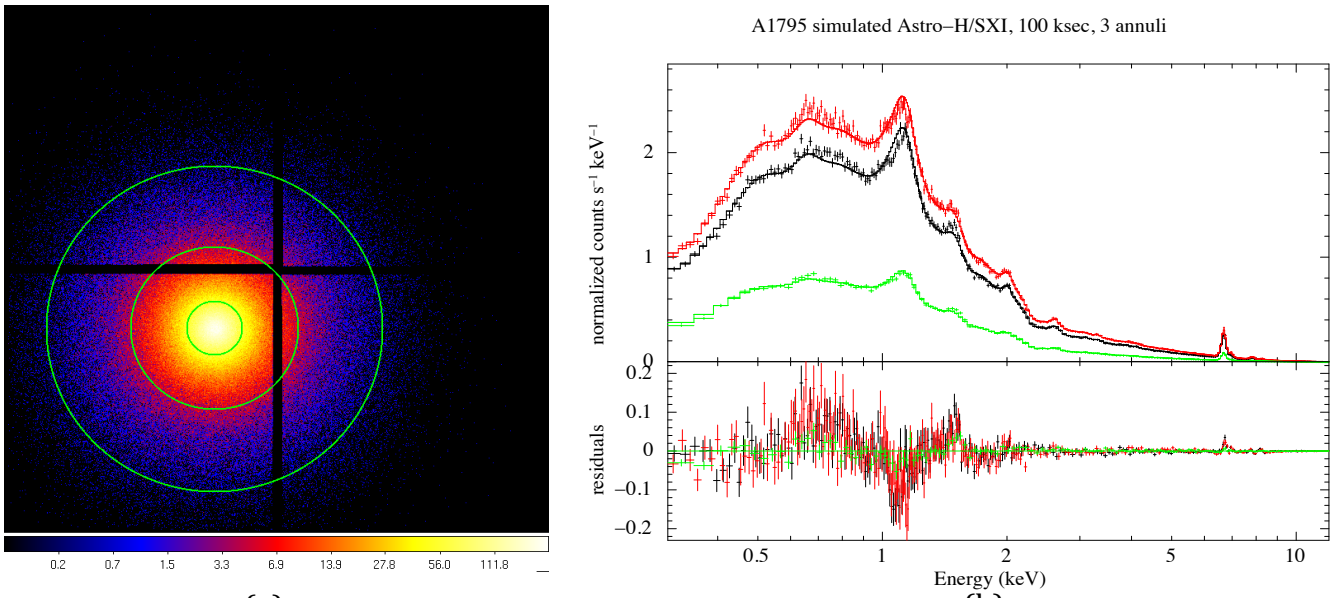
%> sh cluster_beta_tempgradient_sxi.sh.

```
#!/bin/bash

# This script is configured to simulate a cluster of galaxies
# as a beta-model surface brightness profile with a temperature gradient,
# as observed with ASTRO-H instrument SXI.

root_name="cluster_beta_tempgradient_sxi"

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"                              # mission
instrume="sxi"                                 # instrument
cal_dir="$HEASIM_SUPPORT/$mission/$instrume" # calibration directory
resp_dir="$cal_dir/response"                   # response directory
psffile="$cal_dir/psf/sxt-i_EEF_4p5keV_140617_type1.fits" # psf file
vigfile="$cal_dir/vignette/SXT_VIG_140618_type1.fits"     # vignetting file

if [ $instrume = "sxi" ] ; then
     rmf=$resp_dir/ah_sxi_20120702.rmf
     arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
elif [ $instrume = "sxs" ] ; then
     rmf=$resp_dir/ah_sxs_7ev_20130806.rmf
     arf=$resp_dir/sxt-s_140505_ts02um_intallpxl.arf
fi

ra=207.215
dec=26.588
sourcefile="${root_name}.dat"
outfile="output/${root_name}.fits"
logfile="output/${root_name}.log"

punlearn heasim
```

```
pset heasim mission=$mission
pset heasim instrume=$instrume
pset heasim filter=none
pset heasim instmode=none
pset heasim rapoint=$ra
pset heasim decpoint=$dec
pset heasim roll=0.00
pset heasim exposure=100000.
pset heasim flagsubex=no
pset heasim subexposure=100000.
pset heasim insrcdeffile=$sourcefile
pset heasim outfile=$outfile
pset heasim psffile=$psffile
pset heasim vigfile=$vigfile
pset heasim rmffile=$rmf
pset heasim arffile=$arf
pset heasim arfrmftol=1.0e0
pset heasim intbackfile=none
pset heasim psbackfile=none
pset heasim difbackfile=none
pset heasim pszbackfile=none
pset heasim dtpileup=0.
pset heasim getinfile=no
pset heasim debug=no
pset heasim clobber=yes
pset heasim seed=1234567890
pset heasim mdbfile=$LHEA_DATA/heasim.mdb

echo "Parameters for heasim:" | tee $logfile
plist heasim 2>&1 | tee -a $logfile
heasim mode=hl 2>&1 | tee -a $logfile
```

C.10.1 Output Images and Spectra

The output SXI counts image is shown in Figure 11, along with spectra extracted from three regions, shown by the green circles. The results from the spectral fitting are shown below; note that an APEC model was used in the spectral fit, while a Raymond-Smith emission model was used in the simulation. This accounts for the large residuals at 1 keV, where the Fe L line complex is modeled differently in the two models.



(a) (b)

Figure 11. SXI image (a) and spectra (b) for output event files from simulation Example 10. Spectra are extracted from inner (black), intermediate (red), and outer (green) regions.

```
#========================================================================
#Model phabs<1>*apec<2> Source No.: 1   Active/On
#Model Model Component  Parameter  Unit     Value
# par  comp
#                            Data group: 1
#   1    1   phabs       nH         10^22    9.42641E-03  +/-  3.07158E-04
#   2    2   apec        kT         keV      4.74659      +/-  2.05645E-02
#   3    2   apec        Abundanc            0.938391     +/-  1.30408E-02
#   4    2   apec        Redshift            0.0          frozen
#   5    2   apec        norm                2.01809E-02  +/-  7.46185E-05
#                            Data group: 2
#   6    1   phabs       nH         10^22    9.42641E-03  = 1
#   7    2   apec        kT         keV      5.28440      +/-  2.27364E-02
#   8    2   apec        Abundanc            0.953825     +/-  1.47304E-02
#   9    2   apec        Redshift            0.0          = 4
#  10    2   apec        norm                1.71915E-02  +/-  6.62089E-05
#                            Data group: 3
#  11    1   phabs       nH         10^22    9.42641E-03  = 1
#  12    2   apec        kT         keV      4.50434      +/-  3.42118E-02
#  13    2   apec        Abundanc            0.898869     +/-  2.10351E-02
#  14    2   apec        Redshift            0.0          = 4
#  15    2   apec        norm                6.87775E-03  +/-  4.06757E-05
#________________________________________________________________________
```

C.11 Extended Source – Galaxy Cluster Turbulence: User Spectrum that Includes Gaussian Broadening

This example simulates a 200 ks SXS observation of a cluster of galaxies with an isothermal plasma distributed following a beta-model surface brightness profile, with an additional velocity broadening of 200 km s^{-1}. This simulates the effects of turbulence as might be observed with the Astro-H SXS.

The file "cluster_beta_tempgradient_sxi.dat" contains the following, which simulates an isothermal beta model within 4 arcmin of the cluster center:

```
# ra,dec,nh,spec,specpar,flux,bpass,specfile,sform,sun,src_spec
# a 1'-core circular beta-model surface brightness distribution
# w/ isothermal temperature, velocity broadening
```
207.215,26.588,1.2e20,user,0.,0.,0.-0.,model_sim.qdp,2,2,extmod(beta,0.67,1.0,1.0,0.0,0.0,4.0)

The user spectrum file `model_sim.qdp` was generated by XSPEC with the following commands:

```
abund angr
xsect bcmc
cosmo 70 0 0.73
model  phabs*bapec
           0.01      0.001           0           0      100000      1e+06
              5       0.01       0.008       0.008          64         64
            0.3     -0.001           0           0           5          5
           0.06      -0.01      -0.999      -0.999          10         10
            200        -10           0           0       1e+06      1e+06
        0.02883       0.01           0           0       1e+20      1e+24
flux .3 10.
energ 0.1 12.1 12000
cpd /xs
setplot command wdata model_sim.qdp
setplot command whead model_sim.pco
pl mod
quit
```

This creates a 5 keV, 0.3 solar abundance plasma emission model at redshift 0.06 with a turbulent velocity broadening of σ=200 km s^{-1} (FWHM = 470 km s^{-1}) and 0.3–10 keV flux of $4x10^{-11}$ erg cm^{-2} s^{-1}. The broadband model spectrum is shown in Figure 12.

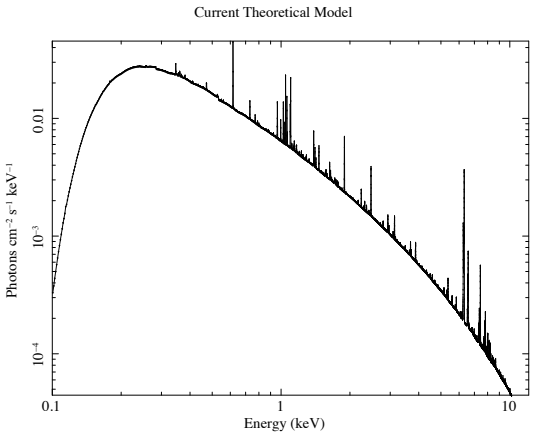


Figure 12. Input spectral model for simulation Example 11.

The following script was used to run *heasim*. The script produces its own logfile, so it can simply be run from the command line via a command like

%> sh cluster_beta_turbulence_sxs.sh.

```
#!/bin/bash

# This script is configured to simulate a cluster of galaxies
# as a beta-model surface brightness profile with a single temperature
# and a single turbulent velocity of sigma = 200 km/s, as observed with
# ASTRO-H instrument SXS.

root_name="cluster_beta_turbulence_sxs"

# if there's no output directory, then make it.
if [ ! -d output ]; then
    mkdir output
fi

mission="astro-h"                              # mission
instrume="sxs"                                 # instrument
cal_dir="$HEASIM_SUPPORT/$mission/$instrume" # calibration directory
resp_dir="$cal_dir/response"                   # response directory
psffile="$cal_dir/psf/sxt-s_EEF_4p5keV_140505_type1.fits" # psf file
vigfile="$cal_dir/vignette/SXT_VIG_140618_type1.fits"     # vignetting file


if [ $instrume = "sxi" ] ; then
     rmf=$resp_dir/ah_sxi_20120702.rmf
     arf=$resp_dir/sxt-i_140505_ts02um_int01.8r_intall.arf
elif [ $instrume = "sxs" ] ; then
     rmf=$resp_dir/ah_sxs_7ev_20130806.rmf
     arf=$resp_dir/sxt-s_140505_ts02um_intallpxl.arf
fi

ra=207.215
dec=26.588
sourcefile="${root_name}.dat"
outfile="output/${root_name}.fits"
logfile="output/${root_name}.log"
```

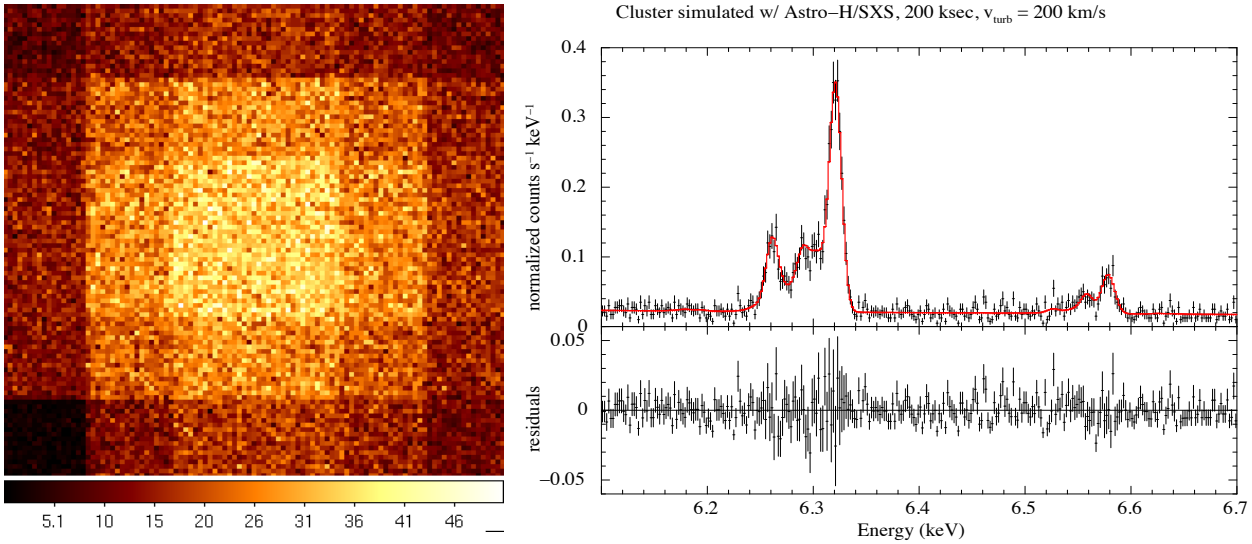
```
punlearn heasim
pset heasim mission=$mission
pset heasim instrume=$instrume
pset heasim filter=none
pset heasim instmode=none
pset heasim rapoint=$ra
pset heasim decpoint=$dec
pset heasim roll=0.00
pset heasim exposure=200000.
pset heasim flagsubex=no
pset heasim subexposure=200000.
pset heasim insrcdeffile=$sourcefile
pset heasim outfile=$outfile
pset heasim psffile=$psffile
pset heasim vigfile=$vigfile
pset heasim rmffile=$rmf
pset heasim arffile=$arf
pset heasim arfrmftol=1.0e0
pset heasim intbackfile=none
pset heasim psbackfile=none
pset heasim difbackfile=none
pset heasim pszbackfile=none
pset heasim dtpileup=0.
pset heasim getinfile=no
pset heasim debug=no
pset heasim clobber=yes
pset heasim seed=1234567890
pset heasim mdbfile=$LHEA_DATA/heasim.mdb

echo "Parameters for heasim:" | tee $logfile
plist heasim 2>&1 | tee -a $logfile
heasim mode=hl 2>&1 | tee -a $logfile
```

C.11.1 Output Images and Spectra

The output SXS counts image is shown, along with an SXS spectrum extracted from the full field of view, in Figure 13. The results from the spectral fitting are shown below. The turbulent broadening is constrained to about +/–10 km s^{-1} at 68% confidence. Also, only about 35% of the original source flux has been detected in the SXS field of view.

```
#========================================================================
#Model phabs<1>*bapec<2> Source No.: 1   Active/On
#Model Model Component  Parameter  Unit     Value
# par  comp
#   1    1   phabs      nH         10^22    2.24365E-02  frozen
#   2    2   bapec      kT         keV      5.07726      +/-  0.156324
#   3    2   bapec      Abundanc            0.313433     +/-  1.41622E-02
#   4    2   bapec      Redshift            6.00023E-02  +/-  3.96415E-05
#   5    2   bapec      Velocity   km/s     212.444      +/-  11.1665
#   6    2   bapec      norm                1.02655E-02  +/-  4.52723E-04
#_____________________________________________________________________________
#
#Fit statistic : C-Statistic = 768.58 using 799 PHA bins and 794 degrees of
freedom.
#
#XSPEC12>error 1. 2 3 4 5 6
```

```
# Parameter   Confidence Range (1)
#      2        4.9259      5.23783    (-0.151378,0.160556)
#      3      0.299617     0.327886    (-0.0138172,0.0144511)
#      4      0.059967    0.0600409    (-3.52434e-05,3.86395e-05)
#      5       201.663      223.751    (-10.7822,11.3056)
#      6    0.00982127    0.0107237    (-0.000444211,0.000458243)
#XSPEC12>flux .3 10.
# Model Flux 0.0056571 photons (1.4037e-11 ergs/cm^2/s) range (0.30000 -
10.000 keV)
```



(a) (b)

Figure 13. SXS image (a), and spectrum zoomed in on Fe K line region (b) for output event files from simulation Example 11.